GAS BUBBLE DISEASE MONITORING AND RESEARCH OF JUVENILE SALMONIDS

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Executive Summary

This document describes the activities of the USGS, Biological Resources Division, Columbia River Research Laboratory relative to Bonneville Power Administration project "Gas Bubble Disease Monitoring and Research of Juvenile Salmonids" (BPA Project No. 96-021 Contract No. 96-AI-93279) for the 1996-97 contract year. This report is composed of three chapters which contain data and analyses of the three main elements of the project: field research to determine the vertical distribution of migrating juvenile salmonids, monitoring of juvenile migrants at dams on the Snake and Columbia rivers, and laboratory experiments to describe the progression of gas bubble disease signs leading to mortality. The major findings described in this report are.

- A miniature pressure-sensitive radio transmitter was found to be accurate and precise and, after compensation for water temperature, can be used to determine the depth of tagged-fish to within 0.32 m of the true depth (Chapter 1).

- Preliminary data from very few fish suggest that depth protects migrating juvenile steelhead from total dissolved gas supersaturation (Chapter 1).

- As in 1995, few fish had any signs of gas bubble disease, but it appeared that prevalence and severity increased as fish migrated downstream and in response to changing gas supersaturation (Chapter 2).

- It appeared that gas bubble disease was not a threat to migrating juvenile salmonids when total dissolved gas supersaturation was < 120% (Chapter 2)

- Laboratory studies suggest that external examinations are appropriate for determining the severity of gas bubble disease in juvenile salmonids (Chapter 3).

- We developed a new method for examining gill arches for intravascular bubbles by clamping the ventral aorta to reduce bleeding when arches were removed (Chapter 3).

- Despite an outbreak of bacterial kidney disease in our experimental fish, our data indicate that gas bubble disease is a progressive trauma that can be monitored (Chapter 3).

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Chapter 1

Vertical and Horizontal Distribution of Individual Juvenile Salmonids Based on Radiotelemetry.

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Abstract

A miniature pressure-sensitive radio transmitter (tag) was evaluated and field tested. The tag had an output voltage of 3.3 V and dimensions of 23 mm x 7 mm with a weight of 2.2 g in air. Tag life decreased as the interval between tag pulses decreased with depth; it was expected to be approximately 11 d at the water surface and 7.5 d at 10.5 m. The tags were accurate to within 16 mm with 95% of observations within ± 0.32 m of the true depth. The resolution of the tag was 0.2 m Errors in indicated depth resulting from differences between working and calibration temperatures were reduced using a correction factor. Tags implanted in juvenile steelhead indicated a depth 0.2 m less than the same tags in water. This difference was not affected by pressure or temperature and was rectified by applying a correction factor to data from tags in fish. A test tag in McNary reservoir was detected from 1,133 m away at a depth of 2 m and 148 m away at a depth of 14 m. Three of eleven fish tagged were tracked from a boat from release in the Ice Harbor Dam tailrace to the McNary Dam forebay. The indicated depths of these fish ranged from -0.23 m to 9.54 m, with median depths ranging from 1.08 m to 4.27 m. Median total dissolved gas (TDG) at the fish locations ranged from 119.8% to 125.8%. Hydrostatic pressure at the median fish depths reduced the median TDG experienced by the fish to between 82.4% and 107.4%.

Objective 1. Test a newly developed depth-sensing radio transmitter for use in juvenile salmonids. Tests will determine accuracy and precision of the depth-sensing component of the transmitter, tag attachment/implantation methods, tag effects on fish buoyancy, and the effects of tag depth on the attenuation of the radio signal from the tag.

Task 1.1. Determine accuracy and precision of reported depths.

Task 1.2. Determine the effects of tag implantation on the accuracy of reported depths.

Introduction

Several methods have been used to determine the depths of freshwater fishes - ranging from the simple to the complex, with vertical gill nets and hydroacoustics the most common (Smith 1974; Witherell and Kynard 1990; Thome et al 1992). Telemetry of individuals has also been used, but past technology has limited this application to use on large fishes due to the size of the transmitters (Gray and Haynes 1977). New advances in this technology have enabled the construction of a pressure-sensitive radio transmitter (tag) of a size suitable for use in juvenile salmonids. The goal of this study was to test a prototype tag and determine its applicability for use in juvenile steelhead during their downstream migration.

Tag Description

We used a tag manufactured by Advanced Telemetry Systems of Isanti, Minnesota, USA[1]. It was based on a 149 MHz 3-battery design with a 300~mm antenna. A pressure transducer, voltage regulator, and circuitry to alter the pulse interval (interval) based on changes in pressure were added to indicate depth. The interval decreased in increments of 8 milliseconds (ms) as pressure increased, equivalent to a column of fresh water approximately 0.2 m in height. The interval was updated with data from the pressure circuit once every 10 seconds. The pressure transducer had an advertised working range of 0-l .7 atmospheres (ATM), equal to the hydrostatic pressure of fresh water at depths of 0- 17.6 m The transducer dimensions were 5.0

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[1] Reference to trade names does not imply endorsement by the United States Government.

mm x 3.0 mm with a weight of 0.24 g in air. The complete prototype tag had a signal output of 3.3 V and dimensions of 23 mm x 7 mm with a weight of 2.2 g in air. The life of the tag decreased as the interval decreased with depth; it was expected to be approximately I1 d at the water surface and 7.5 d at 10.5 m. We did not test the tag life.

Methods

Accuracy and Precision

Accuracy and precision of indicated depths were determined from five tags. The tags were tested in a pressure chamber that was 97 mm in diameter and 230 mm long. The chamber was constructed of Schedule 40 polyvinyl chloride (PVC) pipe. A pressure source and a pressure relief valve were attached to the chamber with a tee fitting at one end and a screw cap was fitted to the other end to allow access to the inside of the chamber. The pressure applied from a cylinder of compressed nitrogen was controlled using a pressure regulator and gauge certified to accuracy within 0.01 ATM.

Accuracy and precision at water temperatures of 10 C, 13 C, and 20 C were determined over a range of pressures from 0- 1.63 ATM. Tests were conducted by placing all five tags in the chamber together. The tags were placed into the chamber filled with water of the desired temperature after which the chamber was sealed and placed in a water bath to maintain the desired temperature during testing. Temperatures varied approximately 0.5 C during each of the 10 trials. The interval was recorded from each tag at 0, 0.27, 0.54, 0.82, 1.09, 1.36, and 1.63 ATM. We recorded the interval in ms rather than the pulse rate in beats per minute because it is a more accurate measure (e.g., there is a 17 ms difference between pulse rates of 59 and 60 beats per minute).

The pressures applied and intervals were expressed as their equivalent depths in fresh water (1 ATM = 10.36 m) to simplify interpretation. The results of regression analyses based on the data recorded at each temperature and pressure were used as calibration curves to convert the interval reported from each tag to indicated water depths (calibration curves were also provided by the manufacturer). Data from each tag was pooled prior to analysis.

Accuracy was measured as the value of the indicated depth minus the applied depth.

Precision was determined as the standard deviation of the indicated depth at each temperature and pressure. Pearson product-moment correlations were used to determine if accuracy and precision were correlated with temperature or pressure. Statistical significance was assumed whenp 1 0.05.

Effects of tag implantation on accuracy

Tags from accuracy and precision trials were used to determine the effects of tag implantation on indicated depth. The tags were implanted in juvenile steelhead (test group) and subjected to four pressure trials similar to those used to determine tag accuracy and precision, except that only one fish was placed in the chamber during each trial. Data collected from the tags during accuracy and precision tests were used as the control group. The indicated depths of test and control groups were compared using a 2-way general linear model (GLM) testing the fixed effects of treatment and pressure. The trials were conducted at 13 C.

The tags were surgically inserted into the body cavity ofjuvenile steelhead from Washougal State Trout Hatchery (Washington Department of Fish and Wildlife) using methods described in Summer-felt and Smith (1990). Antennas were left trailing posteriorly from a small incision in the left side of the body using a shielded-needle technique (Ross and Kleiner 1982). Fish were anesthetized in a 20-L bucket using a solution of 50 mg/L MS-222. Once equilibrium was lost fish were moved to a surgical table fitted with a gravity-fed system capable of irrigating the gills of the fish with 30 mg/L MS-222, fresh water, or any combination of the two via a small tube inserted in the mouth of the fish. The solution was switched from the anesthetic to fresh water when the surgical procedure was near completion. Fish were placed in a 20-L bucket containing aerated fresh water for recovery and were typically swimming upright in less than one minute. Test fish were fasted for approximately 24 h prior to tagging and were allowed to recover from the tagging procedure for about 24 h prior to testing. The mean length and weight of the fish tagged were 2 13.6 mm and 93.2 g, respectively.

Effects of temperature on calibration

The effects of temperature on indicated depth were tested at 10 C, 13 C, and 20 C. Data from the accuracy and precision trials were used for this purpose. The calibration curves for each tag at 10 C were used for all temperatures and relations between indicated and actual depth were examined. Data from each tag were pooled for analysis. An analysis of covariance with actual depth as the factor and temperature as the covariate was used to determine if significant differences existed in slopes and intercepts of calibration curves at each temperature.

An equation was developed to correct errors in reported depths resulting from differences between working and calibration temperatures. The equation data were mean errors in reported depths based on calibrations at 10 C and working temperatures of 10 C and 20 C. Errors in reported depths at a working temperature of 13 C were used to test the equation.

Results

Accuracy andprecision

There were no significant correlations between accuracy or precision with pressure or temperature (Figure 1). Data from each temperature and pressure were pooled to determine the overall accuracy and precision of the tags.

The overall accuracy was + 0.016 m, with a 95% confidence interval of + 0.005 m to + 0.026 m This result was significantly greater than zero indicating there was a positive bias in the indicated depth (t-test, df = 1049, p = 0.0034). The statistical significance of this small value can be attributed to the large sample size (n = 1050) and resulting high power of the test. The precision was 0.166 m, with a 95% confidence interval of 0.148 m to 0.184 m. Ninety-five percent of observations occurred within ± 1.96 SD, or ± 0.32 m; this is equal to ± 1.8 % of the full-scale value of the pressure transducer. The resolution of the tags was 0.2 m, equal to 1.1 % of the full-scale value of the pressure transducer.

Effects of tag impIantation on accuracy

The results from tags implanted in fish differed significantly from those of the control group (Figure 2; n = 490, df = 1, p = 0.0001). There was no significant effect of pressure or the treatment X pressure interaction term, indicating the difference between treatments was equal across all pressures tested. The depths from the test group were an average of 0.2 m less than controls. This was due to an average 8.66 ms difference in the interval of test and control groups, indicating the pressures inside the fish were lower than outside the fish. The test and control groups were not significantly different after a correction was applied by subtracting 8.66 ms from the results of the test group (2-way GLM, $n = 490$, df = 1, $p = 0.9999$).

Effects of temperature on calibration

There was a significant effect of temperature on results from the tags. The interval decreased as temperature increased. Results of an analysis of covariance indicated each temperature required a calibration with different intercepts and slopes. The errors resulting from differences between calibrated and actual temperatures are depicted in Figure 3. The largest average errors resulting from using a 10 C calibration at 13 C and 20 C were + 0.34 m and + 0.76 m, respectively, occurring at the greatest depth tested (16.9 m).

An equation describing correction factors for differences between working and calibration temperatures was developed. The equation was:

$$\text{adjustment} = 0.041 - (0.008 * \text{tdiff}) + (0.005 * \text{interaction term}),$$

where tdiff = (working temperature in C - 10) and the interaction term = (tdiff * indicated depth in meters); df = 13, $R^2 = 0.98$, $P = 0.0001$. The adjustment was subtracted from the reported depth to arrive at the corrected depth. This function reduced errors from temperature differences to a maximum of 0.1 meters over all pressures and temperatures tested (Figure 3).

Discussion

The prototype tags used in 1996 were accurate and precise. Ninety-five percent of observations occurred within 1.96 SD of the mean or $\pm$ 0.32 m, without biologically-significant bias in indicated depth.

This accuracy and precision is similar to other commercial pressure-sensitive telemetry equipment. The Sonotronics (Tucson, Arizona, USA) DT-96 depth tag and Vemco (Armdale, Nova Scotia, Canada) Minilog-TDX each have advertised accuracies of ± 2 % of full scale depth and advertised precisions off 1 % of full scale depth. However, the dimensions of these devices are 16- 18 mm in diameter and 68-95 mm in length, compared to 7 mm x 23 mm for the tag we used. One cost of miniaturization is battery life. The devices from Sonotronics and Vemco have advertised lives measured in years, whereas the tag we tested was expected to last about one week.

The indicated depth was affected by temperature. The effect of temperature was a change in calibration slopes and intercepts. This indicates distinct calibration curves are required for temperature differences of as little as 3 C, the smallest difference in this study. We did not determine the minimum difference in temperature required to produce significant differences in calibration curves.

Tags should calibrated at the temperature at which they will be used. However, this is not always possible in a field situation. Differences is water temperature after fish are released are inevitable and are out of the control of the investigator. A correction factor can be used successfully to reduce these errors.

The effect of a tag being implanted in a fish was a 0.2-m decrease in the indicated depth. The reasons for this difference are unclear. A change in the internal pressure of the fish could have resulted from the surgical procedure, but we cannot confirm this as the internal pressure was not determined prior to the procedure. The pressure difference is almost identical to the resolution of the tags, making it difficult to determine whether or not it should be of concern. We accounted for the difference in pressures by applying a correction factor to the interval of tags in fish used in our field studies. The need for a correction is probably dependent on species, size, and attachment method.

Variability in data can be affected by the radio receiving system. This source of variability can be reduced with proper use of telemetry equipment and knowledge of tag function. Reducing the gain of the receiving system to increase the signal-to-noise ratio and accepting data when the signal was at least 6 decibels (dBm) over the recording threshold of the receiver (“power”=100 on our Lotek SRX-400 receivers) resulted in repeatable data from the tag (see Task 1.4 methods). Using high gain settings and accepting data near the recording threshold resulted in high variability. In addition. the interval varies each time the pressure circuit updates the oscillator (i.e., pulse) circuit. This update occurs once every 10 s, interrupting the last interval of the "old' data, unless the interval was a divisor of 10 s. The result is a short interval once each 10 s. These data should be ignored since they are an artifact of the update mechanism.

We believe the miniature pressure-sensitive radio tag used in this study will be a valuable tool for fishery biologists studying vertical distribution of small fishes. The tag has been miniaturized without compromising accuracy, precision, or resolution of the pressure transducer. We will use this tag in research efforts during 1997 and 1998. The use of this tag in juvenile chinook salmon will be one objective of this work.

Task I. 3. Test the effects of tag implantation on fish buoyancy.

Introduction

An important assumption in radio-telemetry studies is that the tagged fish behave as non-tagged fish. Researchers have studied the effects of various tag weights and attachment methods by comparing the swimming stamina and buoyancy of tagged and untagged fish (Mellas and Haynes 1985; Gallepp and Magnuson 1972). For our purpose, which was primarily to determine the vertical history of tagged individuals. we were most interested in determining the effects of the tag on buoyancy The addition of the tag must not affect fish buoyancy if results of radio-tagged fish are to be used to determine vertical location.

The effects of transmitters on fish buoyancy have been determined using several fish species. Gallepp and Magnuson (1972) studied the effects of negative buoyancy in bluegill ***(Lepomis macrochirus)*** after addition of small weights. Fried et al. (1976) studied the time required for buoyancy compensation after tags were gastrically implanted in Atlantic salmon ***(Salmo salar).*** Both studies found that fish could regain neutral buoyancy following an initial period of negative buoyancy after the addition of weight. The present study was conducted to determine if juvenile steelhead ***(Oncorhynchus mykiss)*** of hatchery origin could regain neutral buoyancy following a recovery period of 24 h after tagging with a newly-developed pressure-sensitive radio transmitter.

Methods

Test fish were juvenile steelhead from the Washington Department of Fish and Wildlife Washougal Trout Hatchery. One hundred and eight fish were transferred from the hatchery to wetlab facilities at the Columbia River Research Laboratory on 09 April, 1996. Fish were kept in 1400-L (0.9 m high x 1.5 m diameter) stock tanks containing single-pass well water at a temperature of 10 C and were fed a diet of commercial moist feed at 2.0 % of body weight per day. Test fish were removed from the stock tank and placed into 270-L (0.7 m high x 0.8 m diameter) holding tanks containing single-pass well water on 02 May 1996 prior to testing on 06 and 07 May. The water temperature was gradually increased to 13 C over a period of 12 h once the fish were in the holding tanks.

The pressure of neutral buoyancy (PNB), as described by Saunders (1965), was used as a measure of fish buoyancy. This is the pressure at which an anesthetized fish rises from the bottom of the test chamber. The PNB is calculated as the atmospheric pressure (AP) minus the reduction in pressure applied (RP) necessary to float the fish (PNB = AP - RP).

Thirty juvenile steelhead were used to test the effects of tag implantation on buoyancy. The fish were split into six holding tanks of five fish each. Fish sizes are listed in Table 1. Sample sizes required were determined based on a power analysis using PNB data from Pinder and Eales (1969). This analysis indicated a sample size of 15 fish per group would result in a statistical power $(1-\beta)$ of 0.8 1 to detect a 10% difference in means when a = 0.05.

Dummy tags were surgically inserted into the body cavity of test fish using methods described earlier in this report The dimensions of the dummy tags were identical to the pressure-sensitive radio transmitters in weight and size. The antennas were cut after implantation so that approximately 2.5 cm protruded from the fish to prevent the antenna from touching the buoyancy chamber, which could affect the results of the test. Test fish were fasted for approximately 24 h prior to tagging and were allowed to recover from the tagging procedure for about 24 h prior to testing. The recovery time allowed fish to recover from the surgical procedure and permitted them to regain neutral buoyancy after addition of the tag (Fried et al. 1976). Fish were allowed access to the air-water interface during this time. Control fish were fasted as the test fish, but were not subjected to the anesthesia or surgical procedures.

Prior to the tests, fish were anesthetized in their holding tanks in a solution of 50 mg/L MS-222; this anesthetic concentration was used throughout the experiment. The anesthetic was added to the water after a screen was placed into the tank to prevent the fish from reaching the surface. Anesthetized fish were then placed into a 20-L bucket containing the anesthetic solution prior to being transferred individually into the buoyancy chamber for testing. Fish were not allowed access to the air-water surface during the transfer to prevent fish from expelling air from or adding air to the swim bladder during this procedure. Testing each fish took approximately 3 minutes.

The buoyancy chamber was identical to that described by Muir et al. (1994). The tank consisted of an acrylic cylinder 30 cm high and 25 cm in diameter filled 80% with the anesthetic solution. Vacuum applied using an electric pump was monitored with a gauge. The local atmospheric pressure was determined from a wall-mounted barometer on site.

Data was tested for normality using the Shapiro-Wilk test. Correlation between PNB and tag weight-to-body weight ratio (weight ratio) was tested using the Pearson product-moment correlation. Statistical significance was assumed when $p \leq 0.05$.

Results

There was no significant difference between PNB of test and control fish (Kruskal-Wallis test, $\boldsymbol{n} = 14$, $\boldsymbol{df} = 1$, $\boldsymbol{p} > \boldsymbol{x}^2 = 0.2686$). A non-parametric test was used to compare the PNB of test and control groups because the data were not normally distributed ($p_{control} = 0.0072$; $p_{test} = 0.3343$). The non-normality was due to one control fish with a PNB of 471.5 (Figure 4A). The data was included in the analysis because it appeared to be valid in every other aspect. Two fish were omitted from analysis: one control fish which was positively buoyant without applying vacuum and one test fish that expelled air from the vent during the test.

The weight ratio of test fish ranged from 2.0% to 3.2% with a mean of 2.6%. There was no correlation between PNB and weight ratio ($\boldsymbol{r} = 0.3226$, $\boldsymbol{p} = 0.2611$; Figure 4B).

Discussion

The use of a 2.2 g tag did not affect the buoyancy of juvenile hatchery steelhead weighing an average of 85 g. This result is not surprising, as the average weight ratio was only 2.6%. Winter (1983) recommended a maximum weight ratio of 2% for telemetry studies, although he did not cite research to support his recommendation. Fried et al. (1976) found that tagged Atlantic salmon smolts with a weight ratio of 6.2% began to regain their buoyancy in as little as 60 min after tag insertion using a gastric method, and provided a regression indicating full compensation may be achieved in about 8 h. We believe juvenile steelhead smaller than 85 g could be implanted with a 2.2 g tag without affecting their buoyancy. This is based on the lack of a relation between weight ratio and PNB in this study. The smallest fish tagged during this study was 69.0 g, resulting in a weight ratio of 3.2 %.

Task 1.4. Determine the effects of tag depth on radio signal reception.

Methods

The distance a tag could be detected based on its depth was evaluated in McNary reservoir. This test was conducted at the mouth of Hat Rock State Park, river kilometer 478, on 25 June 1996 (Figure 6). Water temperature and conductivity during the test were 15 C and 80 μS, respectively.

A tag was lowered along an anchored line in 2 m increments from the water surface to 14 m; the actual depth of the surface measurement was approximately 0.2 m. The spatial location of the tag was determined using a global positioning system (GPS). A boat equipped with a telemetry receiver and 6-element yagi antenna was used to detect the radio signal. The boat, starting far enough away from the tag so that it could not be audibly detected with the receiver, was moved toward the tag location. The position at which the tag could be audibly detected (detected), recorded by the receiver (recorded), and recorded with an omnidirectional signal were determined using a GPS. The distances to detect and record the signal need to be determined because tags can be located with a signal audible to the human ear (approximately -145 decibels;

dBm) before the receiver can detect the signal (approximately -127 dBm) and indicate the interval. An omnidirectional signal indicates the antenna is approximately over the tag.

The gain (i.e., sensitivity) of the receiving system can be varied by the operator to affect the range and directionality of the receiving system. The gain of our system was adjusted so a received signal of - 129 dBm was required to be audibly detected and a received signal of - 115 dBm was required to be recorded by the system to reduce interference from background noise. We determined that a received signal strength approximately 6 dBm over the recording threshold was required to collect repeatable data from the tags (unpublished data), so data with a received signal strength below this limit (i.e., -109 dBm) were ignored.

The effective range of the receiving system was further reduced prior to recording the spatial location of the tag with an omnidirectional signal to enable a more precise location estimate. The system gain was reduced until a received signal of -97 dBm was required to be recorded by the receiver and accepted data from the tag when the received signal was 6 dBm over this threshold (-9 1 dBm) The distances between locations of the boat and tag were determined after differential correction of the GPS data.

Results

Detection distances decreased with water depth (Figure 5). The distance the tag could be detected ranged from 1.133 m at a depth of 2 m to 148 m at a depth of 14 m. The tag at the surface was detected was from a distance of 552 m Data from the tag could be recorded at a distance up to 284 m away (2 m depth). The tag was recorded with an omnidirectional signal from 24 m at the surface to 7 m at a depth of 12 m An omnidirectional signal could not be achieved at the 14 m depth.

Discussion

The attenuation of the radio signal in water decreased the distance tags could be detected with depth This will affect the probability of detecting tagged fish based on their depth; the deeper tags are harder to find. This is a limitation in all studies based on radio telemetry, but gains importance when the objective is to determine the vertical distribution of the tagged animals.

Our data indicates this tag can be detected at distances from 149 m to over 1 kilometer away, depending on tag depth. The maximum detection distance was at 2 m rather than at the water surface, as might be expected, because the transmitting antenna at the surface was less than ½ wavelength (½ wavelength at 150 MHz = 1 m) from the air-water interface barrier. In general, radiating systems should be greater than ½ wavelength from any conductor or barrier to maximize their effectiveness (C. Grant, Grant Systems Engineering, personal communication). The median depth of juvenile steelhead tracked in 1996 was approximately 4 m or less (described later in this report), which would result in detection distances between 552 m and 1.1 km. Tracking protocols will be established based on this data to increase the probability of detection of tagged fish.

We recorded the distances to detect the radio signal, record it, and record it with an omnidirectional signal because this is the method we use in the field. Fish are initially detected at a high gain and their location determined by moving toward the area of the strongest signal while reducing the gain until an omnidirectional signal is achieved at a standard gain. Our data indicates this procedure results in a 2-dimensional fish location to within 7-24 m depending on fish depth. We believe this distance can be reduced, as an omnidirectional signal was not achieved during our test. This was an operator error that will be corrected in the future.

Objective 2. Determine the vertical and horizontal distribution of juvenile steelhead in McNary Reservoir.

Task 2.1. Monitor near-dam horizontal and vertical movements of tagged fish in the McNary Dam forebay using radiotelemetry equipment mounted on McNary Dam.

This task was not initiated due to the lack of funding prior to 05 April, 1996

Task 2.2. Monitor the horizontal and vertical movements of tagged fish between the Ice Harbor Dam tailrace and McNary Dam forebay using radiotelemetry equipment mounted in boats.

Methods

Fish Collection and Tagging

Fish were obtained from the juvenile fish collection facility at Ice Harbor Dam at Snake River kilometer (rkm) 15.6 between 22 May and 26 June 1996 (Figure 6). Migrating juvenile steelhead were removed from the daily sample by Washington Department of Fish and Wildlife personnel and placed in a bucket containing an aerated solution of 30 mg/ L MS-222. Fish released on 19 and 26 June were collected at Lower Monumental Dam and transported to Ice Harbor Dam for tagging and release because there were no juvenile hatchery steelhead available in the collection at Ice Harbor Dam on those dates.

Radio tags were surgically implanted in the abdomen of the fish using the method described earlier in this report. Fish were placed in a tank supplied with river water and allowed to recover 24 hours before release through the bypass flume. The flume released fish on the powerhouse side of the tailrace. Each release was composed of l-3 fish. A total of 11 fish were released.

Mobile Tracking

A boat equipped with a Lotek SRX-400 telemetry receiver and a 6-element yagi antenna was used to track the fish. A Common Sensing model TBO-L total dissolved gas (TDG) meter was used to monitor TDG and water temperature at each fish contact. The reservoir depth was determined using a Humminbird fish finder.

We attempted to contact each fish at approximate one-hour intervals during their migration between the Ice Harbor Dam tailrace and McNary Dam forebay. Fish were located using the method described previously in this report. The interval and signal strength of the radio tag pulse, water depth and temperature, spatial location, total dissolved gas and delta P were recorded on a data sheet and were entered into a hand-held GPS datalogger at each fish contact. The TDG and delta P measurements were taken with the probe at the depth of the fish, as indicated by the tag, or at 5 m, whichever was less. Tracking continued for approximately 12-h on and 12-h off when one 2-person crew was available, or for 24 h per day when two crews were available.

Two methods were used to collect fish depths and locations. We typically attempted to contact each fish and record location, depth, and other information once per hour. We also periodically collected depth information from fish once per minute over a one-h period. Fish depth was the only data recorded during this time. This procedure was repeated during day and night periods, but was used sporadically.

Data analysis

Tag intervals were converted to indicated water depth based on calibration curves determined prior to tag implantation. Calibration equations at 10 C were supplied from the factory, but we performed calibrations after all tags were returned to the factory for repair of a malfunction. Results from the tags were corrected for the effects of temperature and implantation as described earlier in this report.

The uncompensated TDG, calculated as ((fish depth in meters * 9.6 %/m) - TDG%) was used to account for the effects of hydrostatic pressure on the actual TDG to which each fish was exposed (Colt 1984). This is based on the fact that 9.6% of TDG is compensated for by increased gas solubilities by the hydrostatic pressure exerted by a column of fresh water 1 m in height. The compensation depth, based on the same principle, was calculated as the (TDG-100) / 9.6.

Fish depth data was assessed for normality using the Shapiro-Wilk statistic. Measures of central tendency were calculated, plotted and examined for correlations. Significance was assumed when $\boldsymbol{p} \leq 0.05$. The spatial locations of each fish contact were entered into a geographical information system (GIS) database and plotted.

Results

Nine of 11 fish released were successfully tracked from the Ice Harbor Dam tailrace. One fish was dead and one tag was not functioning when released. Of the nine fish tracked, three tags failed, two fish were lost, and one fish was suspected to have been consumed by a Western Grebe ***(Aechmophorus occidentalis).*** The interval of the failed tags was out of the calibrated range and ceased to indicate changes in depth. Three fish were tracked from release to the McNary Dam forebay; two were detected passing through the McNary Dam spillway and one was tracked to

Hat Rock State Park where tracking efforts were terminated. Water temperatures varied from 12.9 C to 16.0 C during tracking.

Hourly depths were collected from each fish between 3 and 39 times, with an average of 16 depth contacts per fish (Table 2). The greatest number of contacts were from the three fish tracked to or near McNary Dam, frequencies 149.483 MHz , 149.58 1 MHz, and 149.8 16 MHz. We collected 26-39 depths and locations from each of these fish. The two fish that were tracked over the spillway at McNary Dam had travel times of 27.4 h (149.816) and 39.2 h (149.483) between Ice Harbor and McNary dams.

Spatial locations of tagged fish are shown in Figures 7-10. No firm conclusions can be made about the behavior of the fish tracked in 1996 due to the small sample size. The two fish we tracked to McNary Dam passed via the spillway. This was confirmed by a person standing on the darn above the spillway with telemetry equipment.

Results of the depths of tagged fish will be limited to the three fish tracked to or near McNary Dam, since most data came from these animals. The median depths of these fish ranged from 1.08 m to 4.27 m during median TDG levels of 119.9% to 125.8% (Table 2). The median uncompensated TDG ranged from 82.4% to 107.4% (Table 2).

The fish depth, reservoir depth, and TDG from each fish contact are illustrated in Figures 1 l-l 3. No clear pattern existed in the depth histories of the three individuals, although a die1 movement of increased depths in the evening was evident in two of the fish (Figures 11 and 12). There did not appear to be a relation between fish depth and TDG.

Minute-by-minute depth histories of one fish are depicted in Figure 14. This data is presented as an example of the type of information that can be obtained from the tags.

Discussion

Depth and TDG information were collected from a small number of tagged fish in 1996 due to the late funding date. Firm conclusions about fish behavior cannot be made from this data because of the small sample size.

The migration depths of the fish reduced the effective TDG exposure by about 24% of saturation. If this occurs in the fish population as a whole it may explain the apparent difference between expected and observed signs of gas bubble disease (GBD) found by the gas bubble monitoring program in the last two years. There has been a great deal of debate over the paucity of signs detected by the monitoring program given the TDG levels present in the reservoir. The migration depths of juvenile salmonids tracked in 1996 suggest that fish depth could be an important factor in explaining such a difference.

Apart from the direct compensation afforded by hydrostatic pressure, Knittle et al. (1980) indicated time at depth also imparts additional protection from GBD. They found that the survival of juvenile steelhead in water at 130% TDG was doubled when they were held at a depth of 3 m for 3 h prior to exposure. The fish we tracked in 1996 reached depths of nearly 10 m on several occasions, which afforded additional protection from GBD. This source of protection or recovery from GBD has not been accounted for in previous studies of GBD in the Columbia basin, but may be a significant factor in reducing GBD.

Three of eleven tags failed shortly after release. The pressure-sensitive component of the tag ceased to alter the interval in these tags. The tags continued to emit a signal, but the interval was out of the calibrated range. The manufacturer is addressing this problem.

Releasing a larger number of tagged fish in future studies will enable conclusions regarding the vertical and horizontal distribution of juvenile salmonids. One outcome of this process will be an “average” depth and TDG history of all fish released. This could be used to directly test the GBD that may be expected to occur under a specific environmental and behavioral scenario. Vertical and horizontal information from tagged fish can also be used in ongoing model development by the U.S. Army Corps of Engineers in an effort to predict fish mortality based on the their exposure to water with high TDG.

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Table 1. Sizes of test and control fish used in buoyancy experiments on 07 May 1996. Lengths are in millimeters; weights are in grams.

	N	Minimum	Maximum	Standard Deviation	Mean
Control					
Fork Length	14	186	230	13.54	207.2
Weight	14	61.5	118.9	17.55	86.2
Test					
Fork length	14	194	215	6.68	203.1
Weight	14	69.0	107.2	10.13	84.2

Table 2. Radio frequency in MHz, length (mm), weight (g), release date and time, total number of contacts (X-Y), number of fish depths recorded, minimum, maximum, and median fish depth (m), median TDG and median uncompensated TDG (percent) of hatchery steelhead released at Ice Harbor Dam during spring, 1996. nd indicates no data available.

Radio Tag Frequency	Date/Time of Release	Fork Length	Weight	X-Y Contacts	Depth Contacts	--- Fish Depth ---- Minimum	Maximum	Median	TDG	Uncompensated TDG
149.873	5/22/96 - 0825	244	120.6	0	0	nd	nd	nd	nd	nd
149.953	6/01/96 - 1120	236	99.5	29	17	0.66	3.38	1.51	118.0	102.6
149.581	6/05/96 - 1032	203	71.5	26	26	-0.07[a]	6.19	2.30	125.8	106.5
149.774	6/05/96 - 1032	197	61.2	12	12	1.04	4.36	1.84	120.3	102.7
149.446	6/12/96 - 0915	228	92.7	3	3	1.13	1.84	1.13	127.3	112.1
149.912	6/12/96 - 0915	213	83.3	3	3	0.78	1.79	1.39	130.9	113.7
149.522	6/19/96 - 1223	241	118.4	6	4	3.50	6.80	4.05	133.9	94.7
149.816	6/19/96 - 1223	273	233.9	29	29	0.08	9.25	4.27	123.0	82.4
149.461	6/26/96 - 1110	231	95.6	0	0	nd	nd	nd	nd	nd
149.483	6/26/96 - 1110	234	101.0	39	39	-0.23[a]	9.54	1.08	119.9	107.4
149.935	6/26/96 - 1110	236	112.9	4	0	nd	nd	nd	nd	nd

[a] Negative numbers are possible near a depth of 0 m due to the accuracy and precision of the tag.

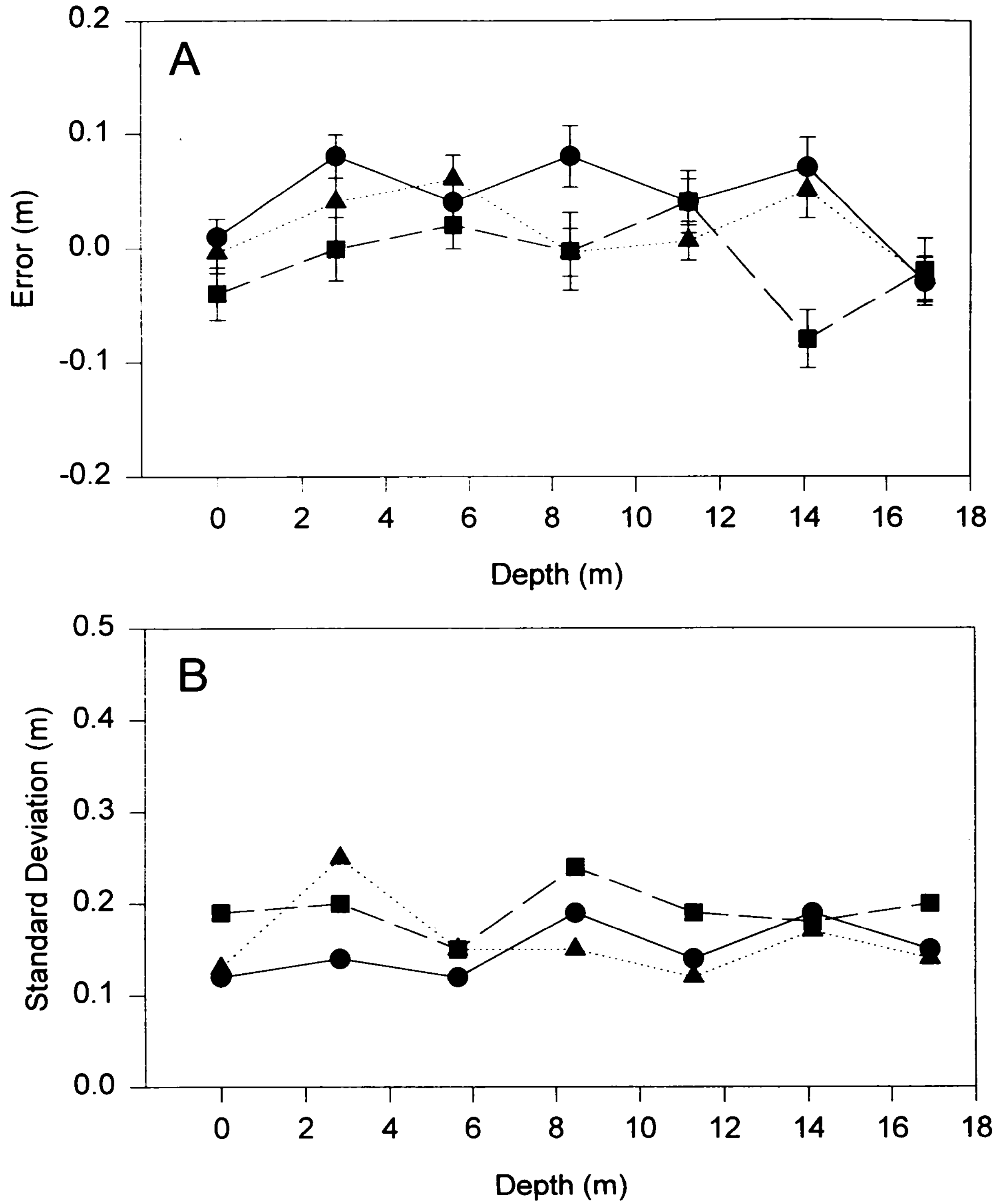

Figure 1. Errors (A) and standard deviations (B) of indicated depths of tags at 10 C (●), 13 C (■), and 20 C (▲) over a range of water depths. Vertical lines in (A) indicate one standard error.

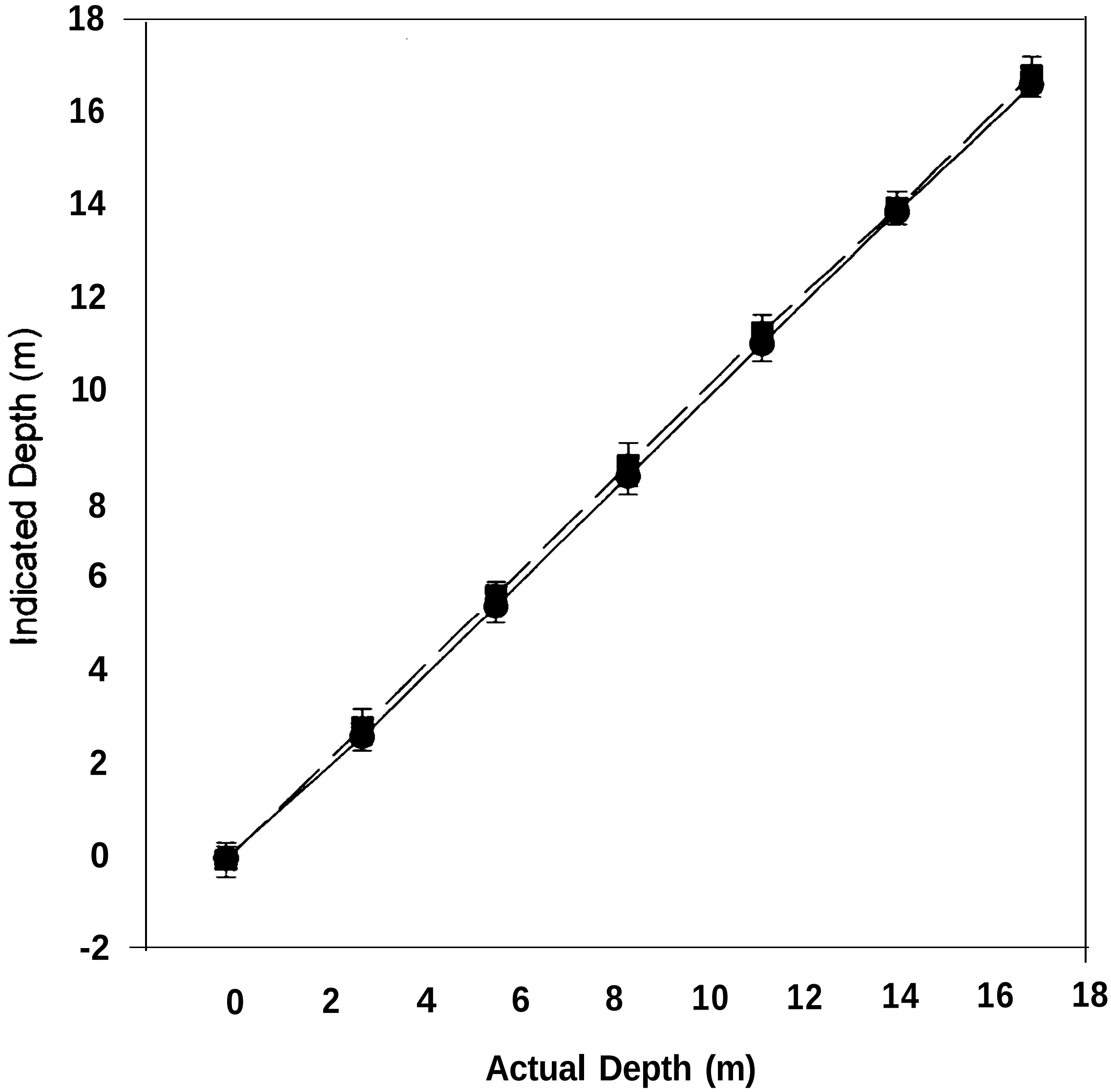

Figure 2. Indicated depths from tags implanted in fish (●) and those in water (■). Vertical lines indicate 95% confidence intervals.

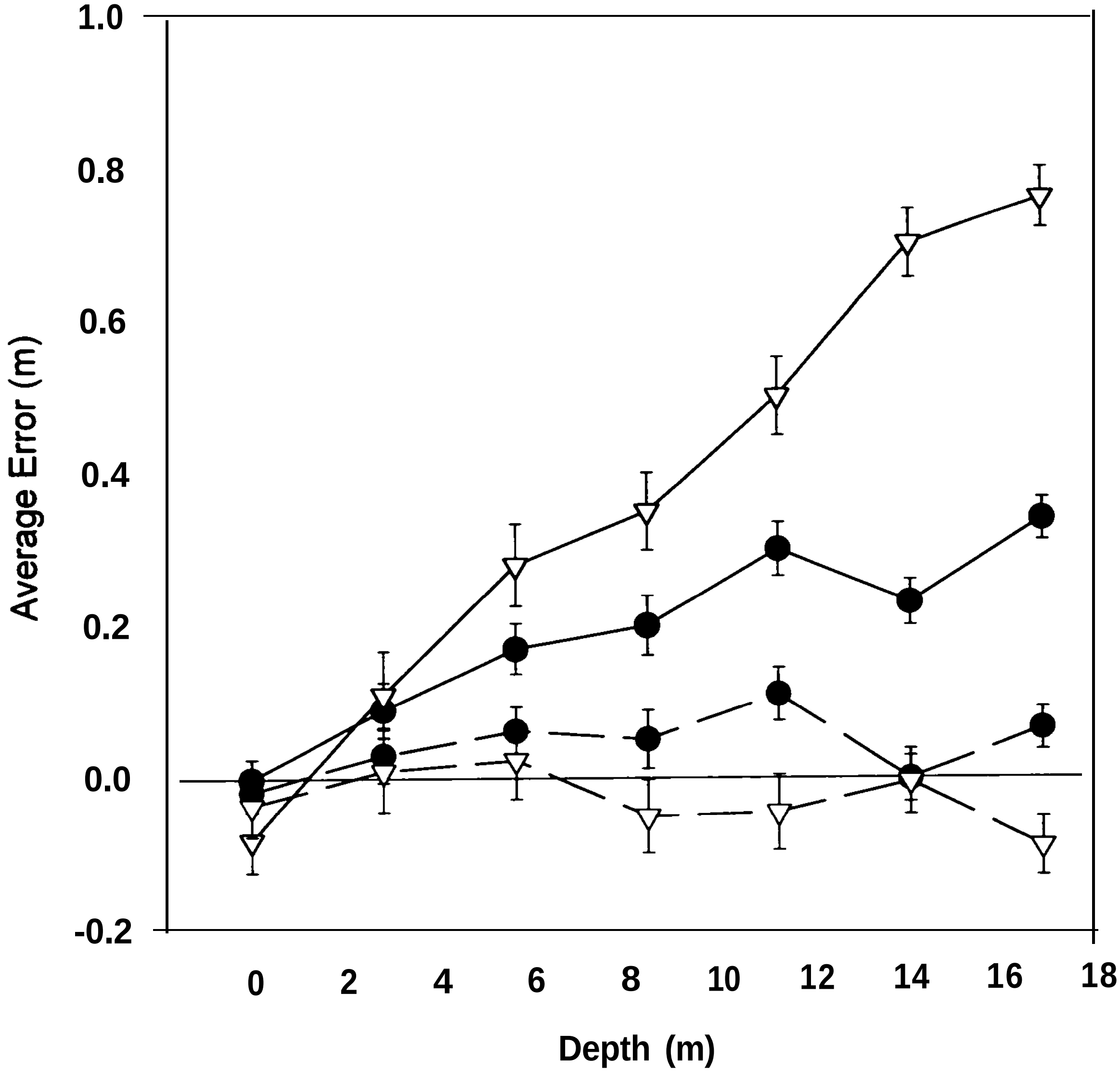

Figure 3. Mean errors in indicated depths from five tags at 13 C (●) and 20 C (∇) based on a calibration at 10 C (solid lines) and errors after corrections using a linear regression (dashed lines).

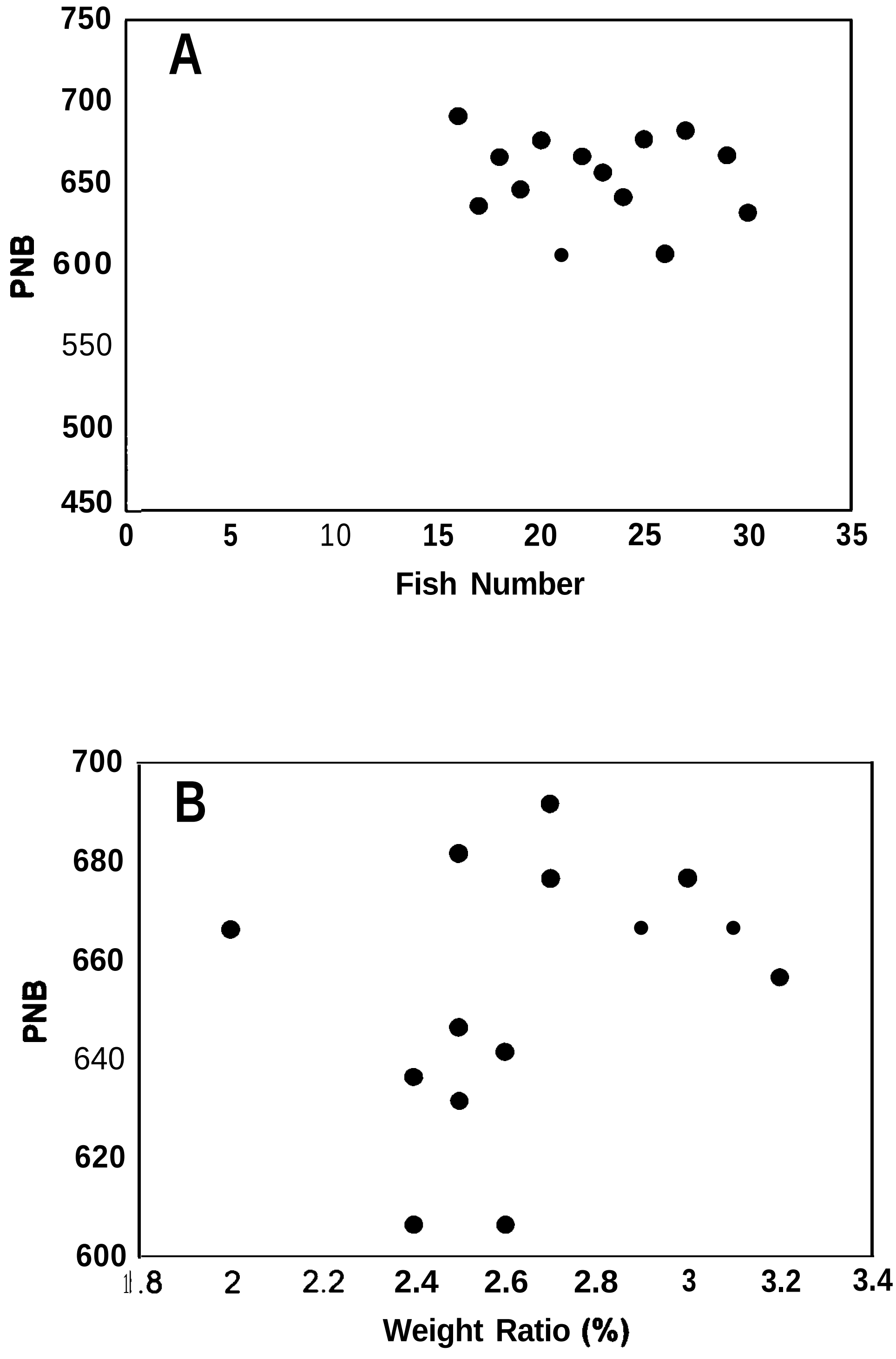

Figure 4. Pressure of neutral buoyancy (PNB) of control (○) and test (●) fish used in buoyancy experiments on 06-07 May, 1996 (A). Fish number is a sequential number reflecting the order fish were tested. Plate (B) depicts the relation of PNB and tag weight to body weight ratio (weight ratio) for test fish implanted with dummy tags.

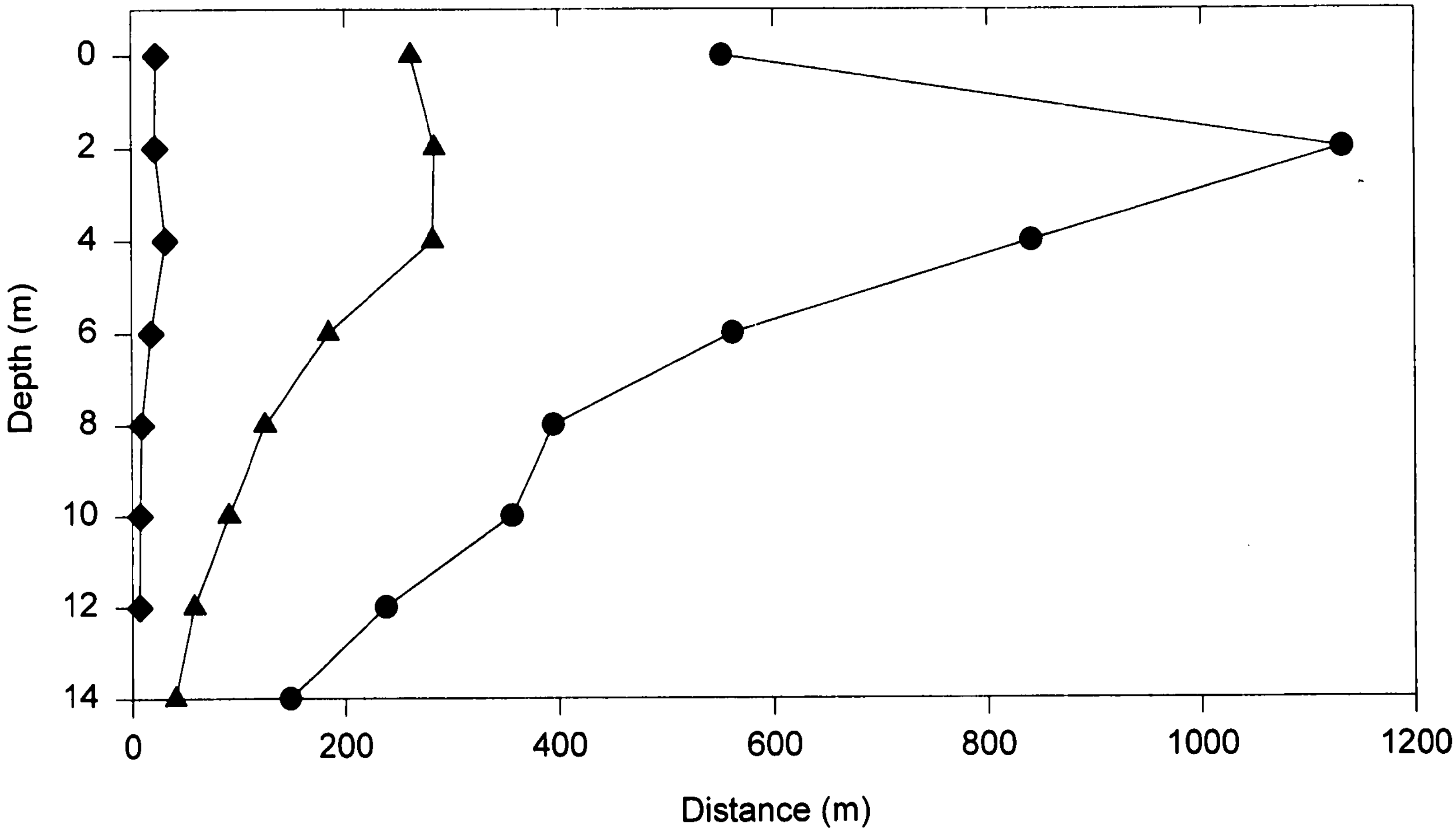

Figure 5. Distances tags were detected (●), recorded (▲), and recorded with an omnidirectional signal (◆) on 25 June, 1996. See text for further description.

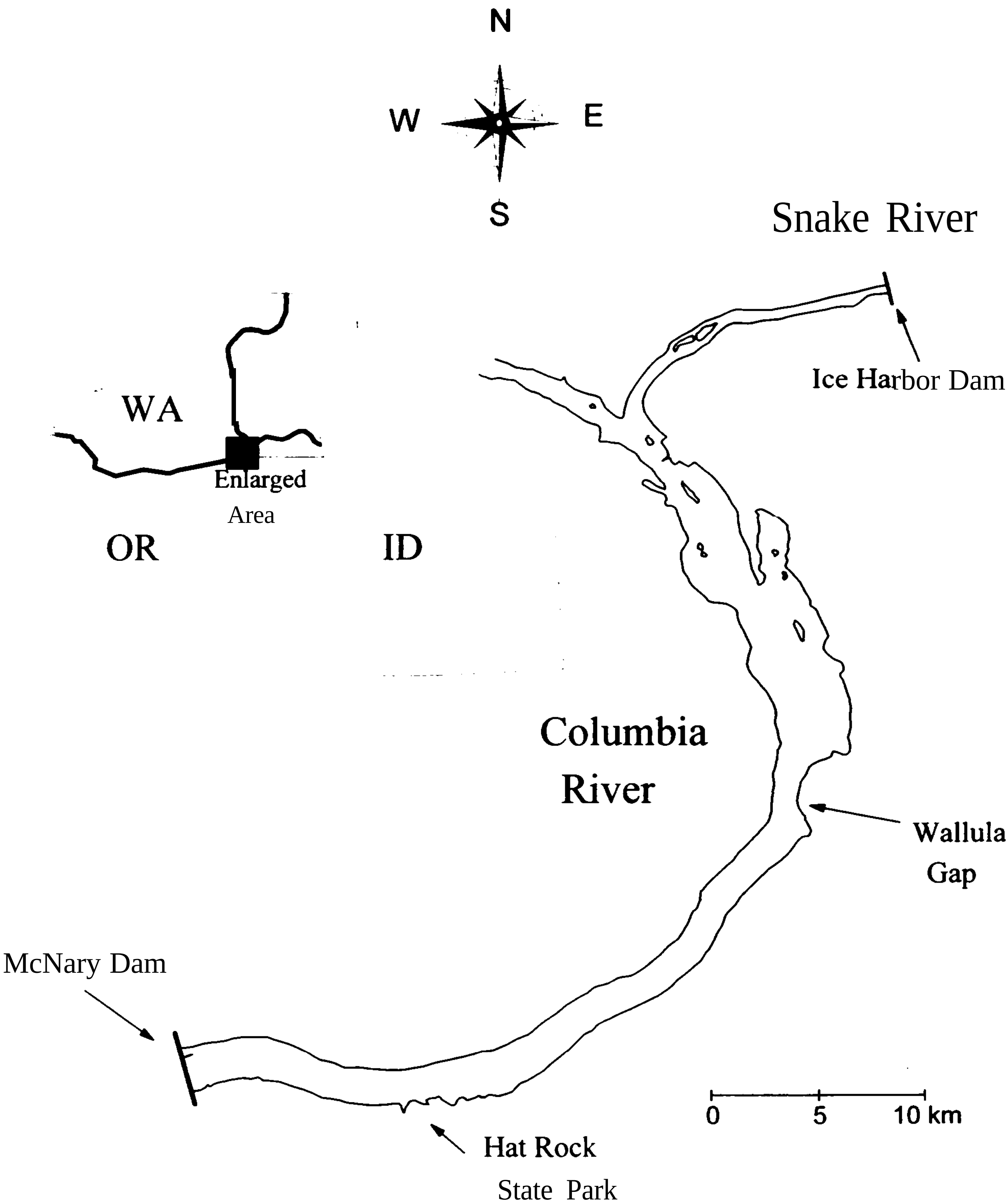

Figure 6. Map of the study area between Ice Harbor Dam and McNary Dam.

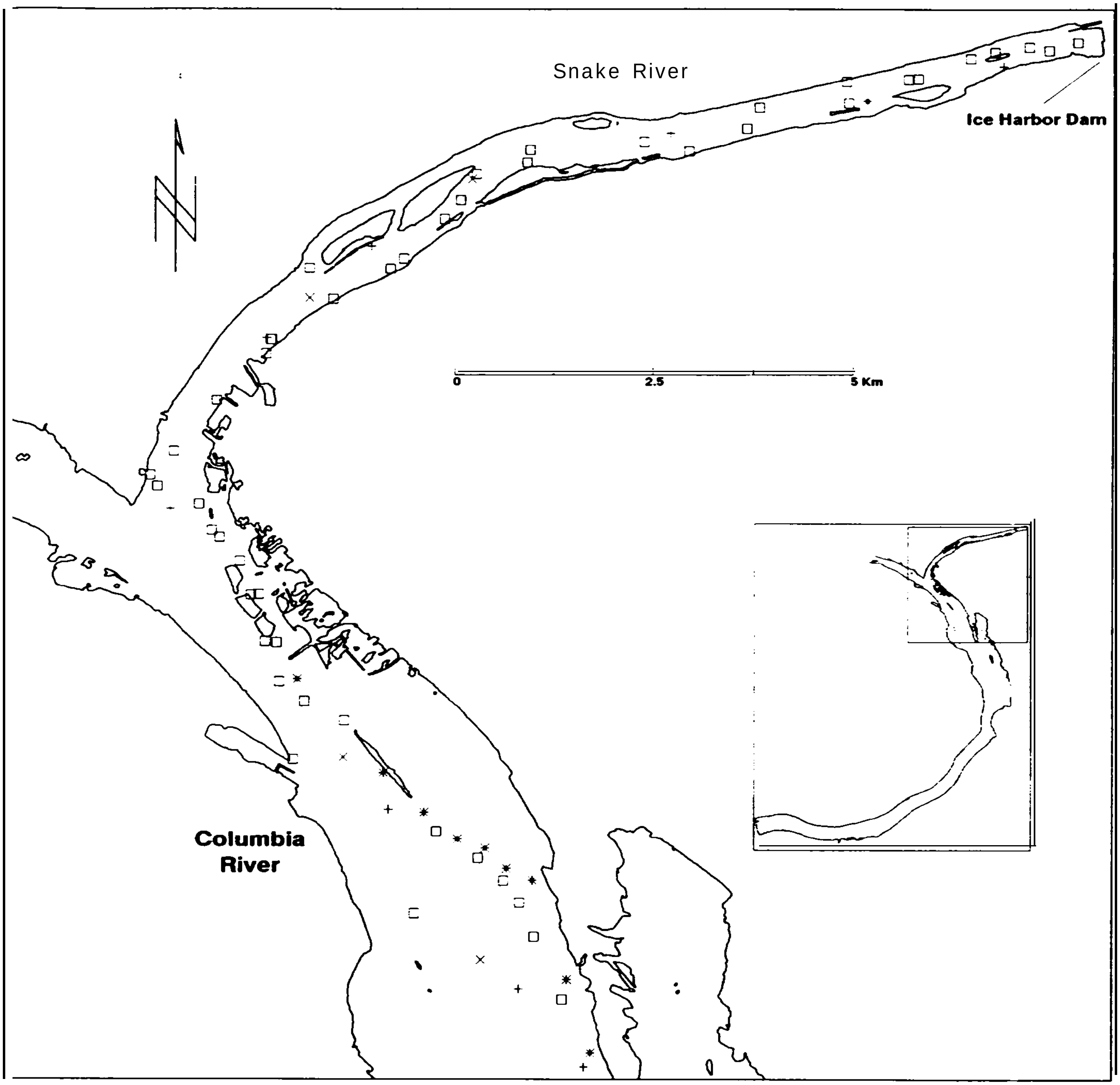

Figure 7. Spatial location of fish 149.483 (+), 149.581 (*), 149.816 (X), and all other fish (□) tracked during spring, 1996. Data from the area indicated by the box in the inset map are shown.

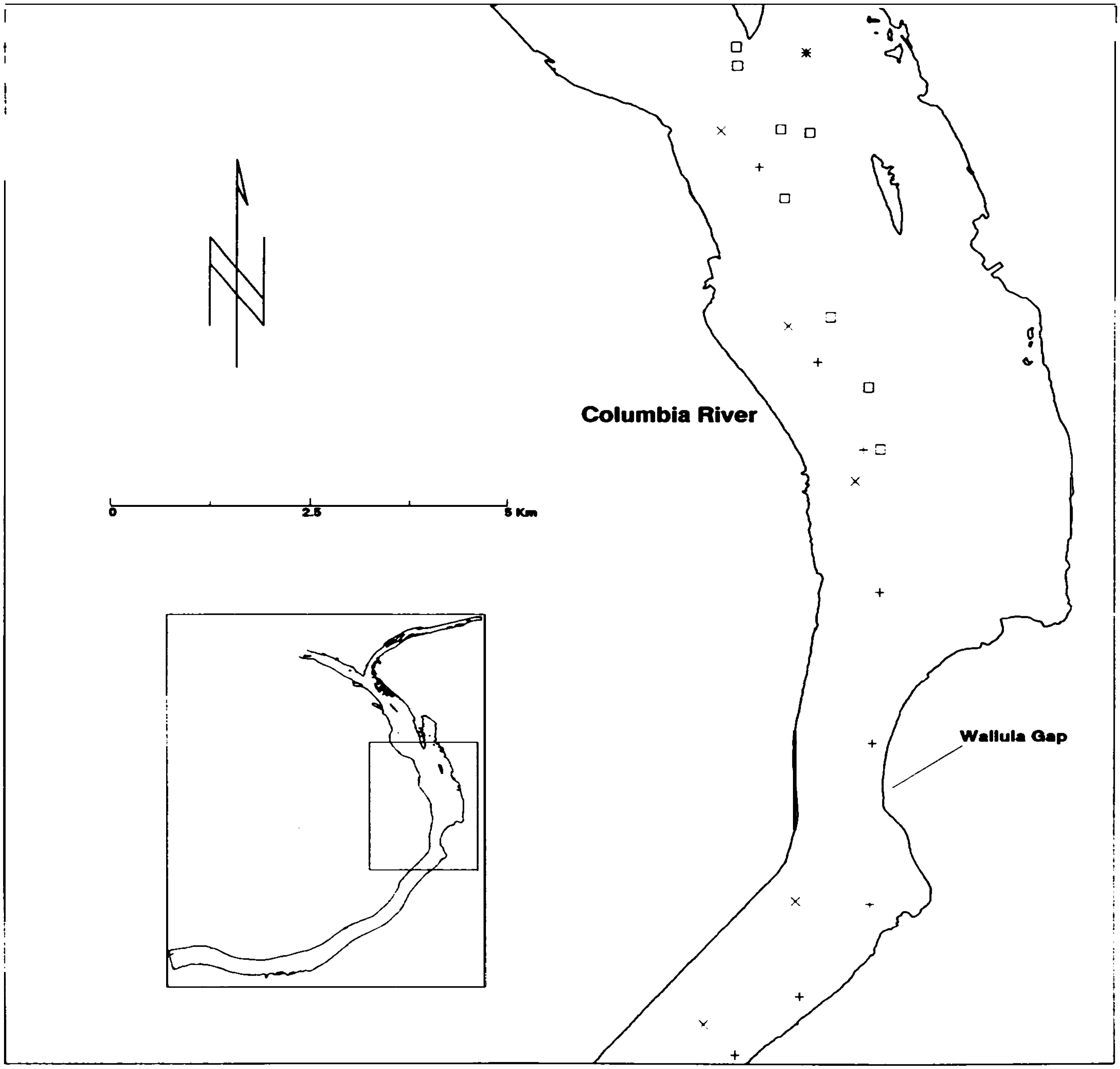

Figure 8. Spatial location of fish 149.483 (+), 149.581 (*), 149.816 (X), and all other fish (□) tracked during spring, 1996. Data from the area indicated by the box in the inset map are shown.

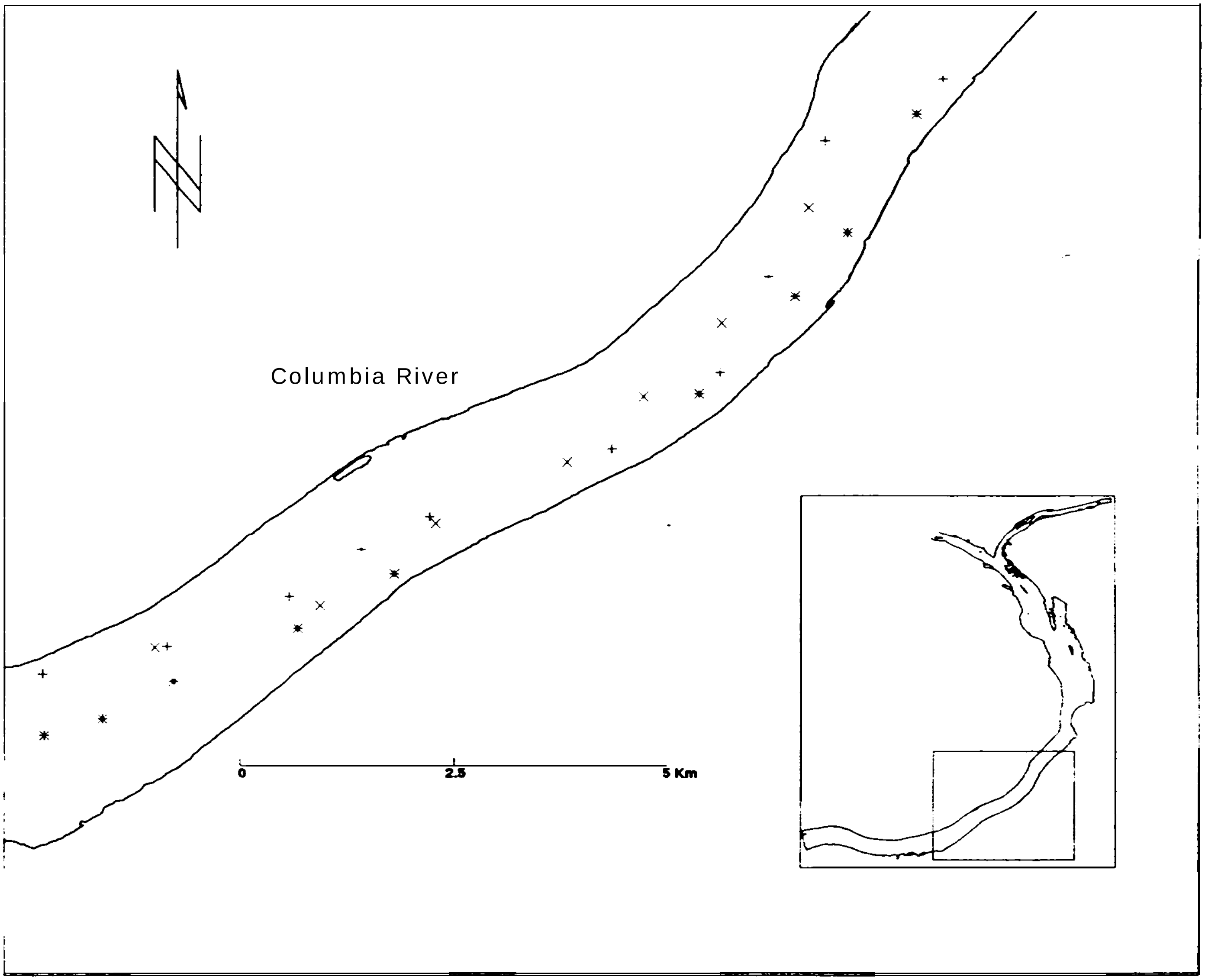

Figure 9. Spatial location of fish 149.483 (+), 149.581 (*), and 149.816 (X) tracked during spring, 1996. Data from the area indicated by the box in the inset map are shown.

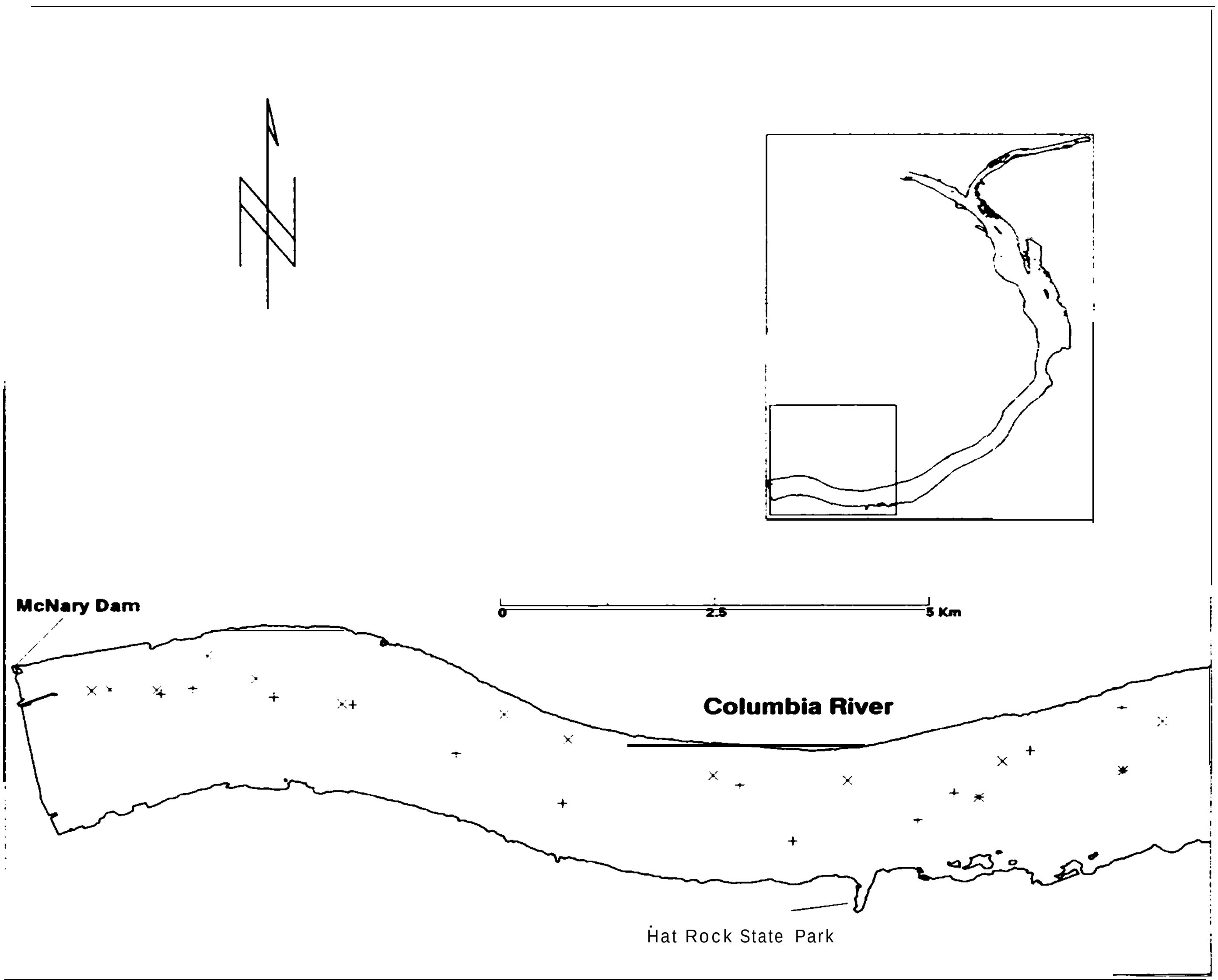

Figure 10. Spatial location of fish 149.483 (+), 149.581 (*), and 149.816 (X) tracked during spring, 1996. Data from the area indicated by the box in the inset map are shown.

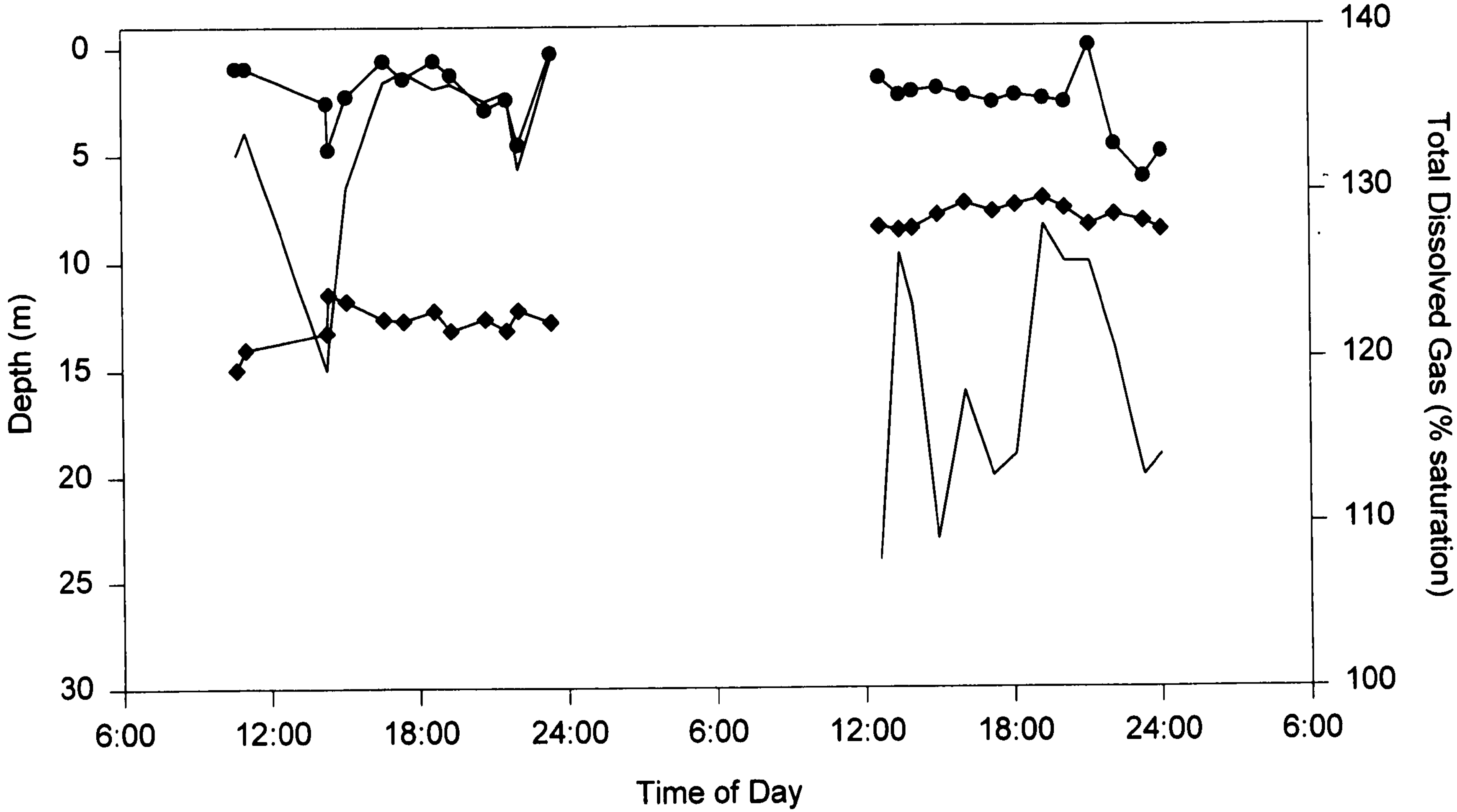

Figure 11. Fish depths (●), reservoir depths (no symbol), and total dissolved gas (◆) at each contact of the fish implanted with tag frequency 149.581 released 05 June 1996 at 1032 h. Data were collected from release in the Ice Harbor Dam tailrace to Hat Rock State Park.

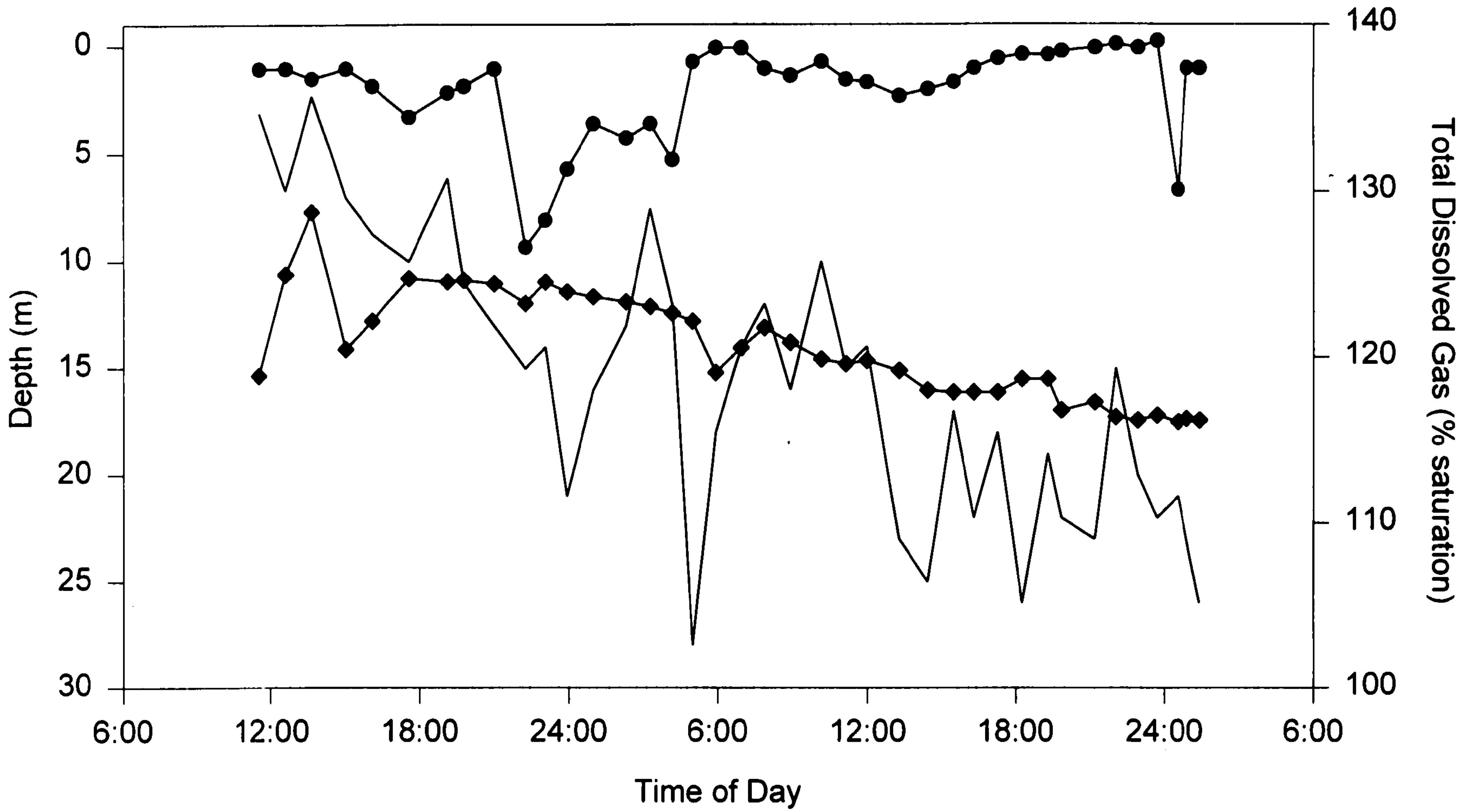

Figure 12. Fish depths (●), reservoir depths (no symbol), and total dissolved gas (◆) at each contact of the fish implanted with tag frequency 149.483 released 26 June 1996 at 1110 h. Data was collected from release in the Ice Harbor Dam tailrace to the forebay boat restricted zone at McNary Dam.

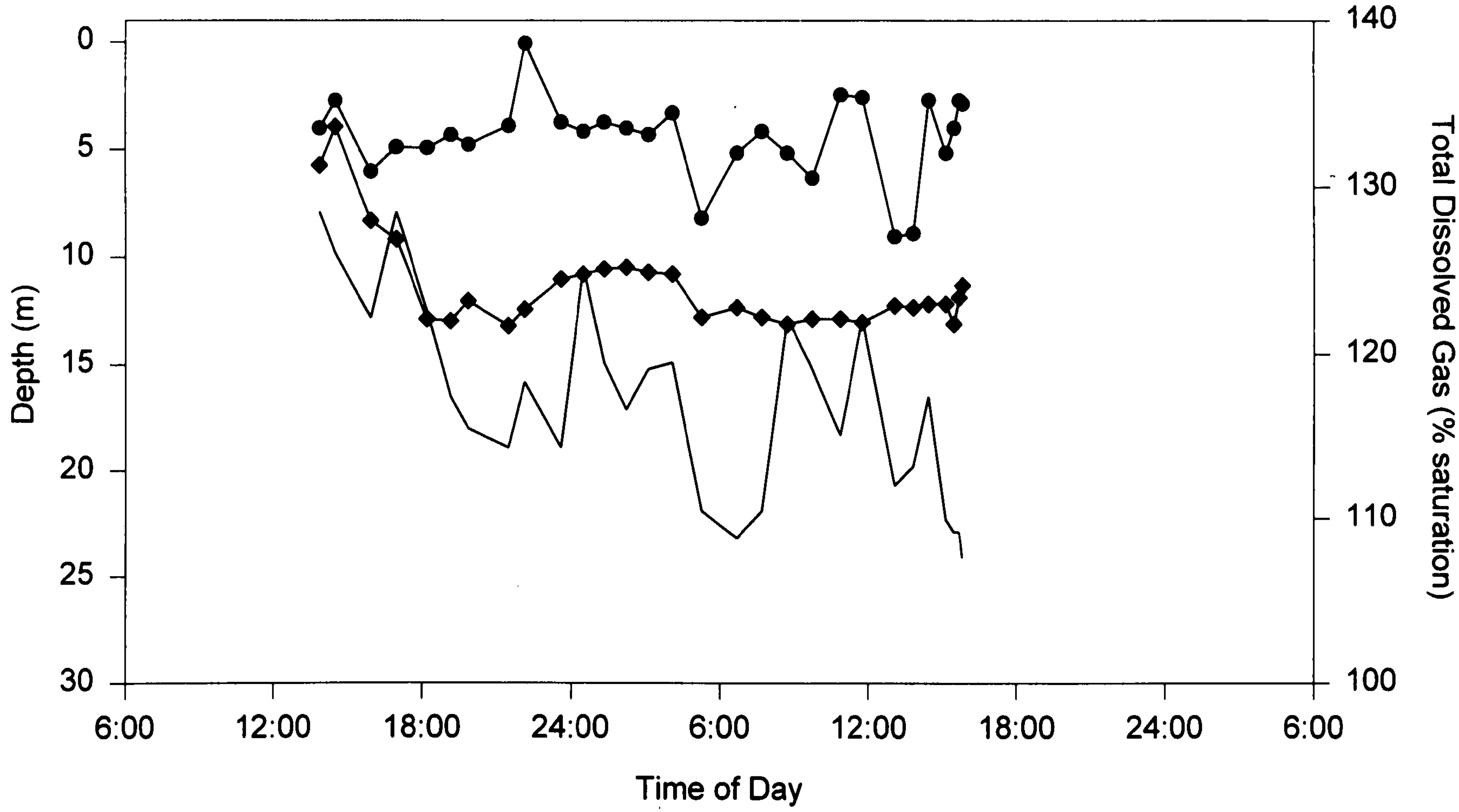

Figure 13. Fish depths (●), reservoir depths (no symbol), and total dissolved gas (◆) at each contact of the fish implanted with tag frequency 149.816 released Dam.19 June 1996 at 1223 h. Data was collected from release in the Ice Harbor Dam tailrace to the forebay boat restricted zone at McNary.

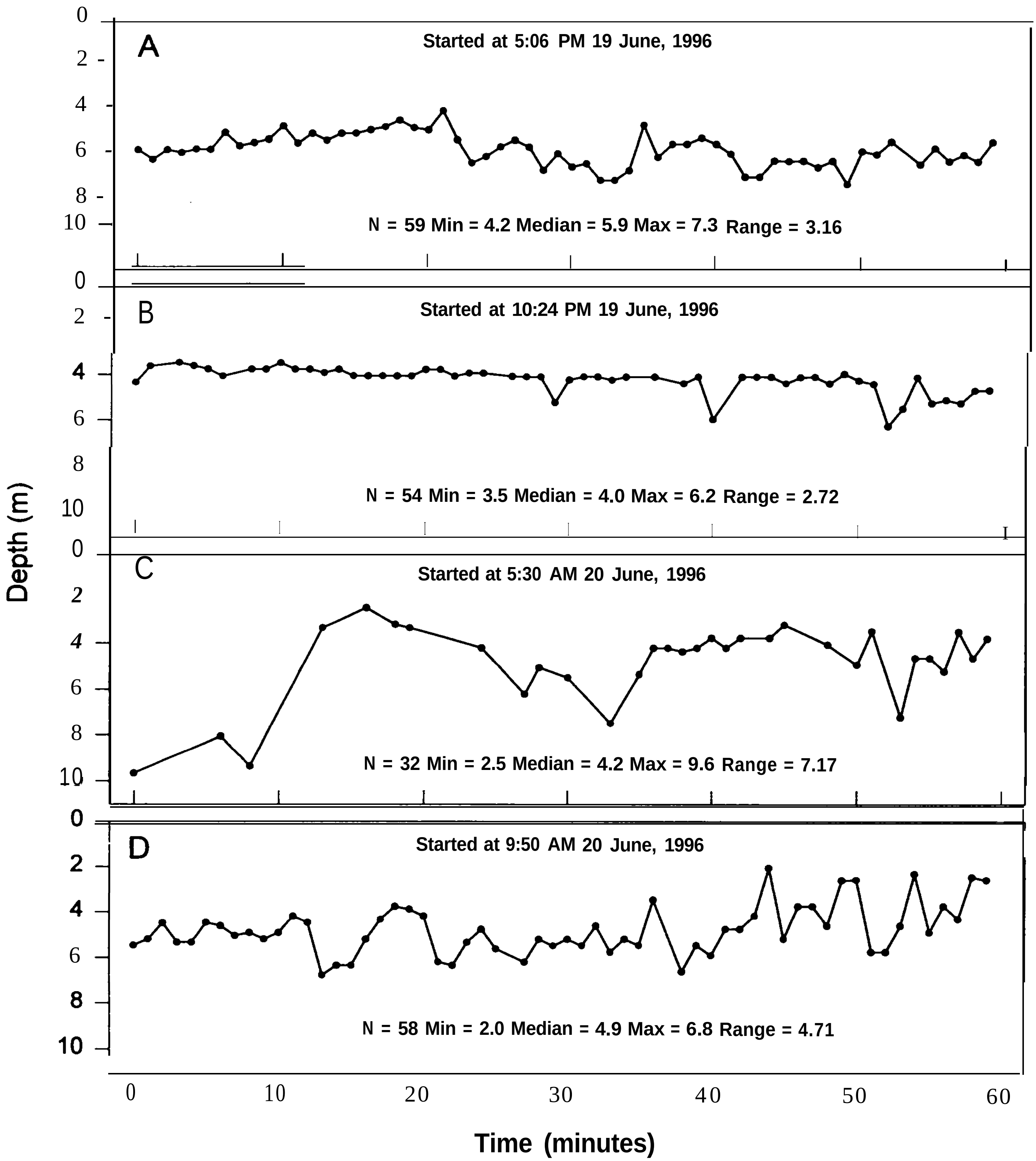

Figure 14. Depths of the fish implanted with tag frequency 149.816. Depths were recorded approximately once-per-minute over a 1 -h time period.

Chapter 2

Gas Bubble Trauma Signs in Juvenile Salmonids at Dams on the Snake and Columbia Rivers

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Introduction

In 1994 a management decision was made to spill water to reduce turbine-related mortality of juvenile salmonids migrating past hydropower dams on the Snake and Columbia rivers. Spilling water over dams can cause gas-supersaturated water which in turn can cause gas bubble disease (GBD) in aquatic organisms. Supersaturated water can be created when air is entrained in water spilling over dams. Gas supersaturation can also exist in natural aquatic environments. In 1995, the Columbia River Research Laboratory developed protocols and monitored juvenile salmonids collected at dams on the Snake and Columbia rivers for signs of GBD.

In 1996, the objectives of this study were to determine the proportion of juvenile salmonids migrating past dams on the Snake and Columbia rivers that had signs of GBD based on non-lethal examination of the lateral line and fins; and to report those data to the Fish Passage Center for inclusion in the GBD-monitoring database. We also coordinated sampling with Dr. Tom Backman, Columbia River Inter-Tribal Fish Commission, who collected smolts from forebays at dams in order to compare prevalence of GBD in fish collected from the river to those collected at dams.

Methods

Fish were collected at Lower Granite, Little Goose and Lower Monumental dams on the Snake River and Rock Island, McNary, John Day and Bonneville darns on the Columbia River. Staff from the Columbia River Research Laboratory (CRRL) and the Smolt Monitoring Program worked together to examine fish. Sampling was conducted 3 days a week when the total dissolved gas (TDG) was below 120%; when TDG was above 120% sampling was conducted 4 days a week. At sites where there were bypass/collection systems, fish were collected from the separator. At John Day and Bonneville dams fish were collected by dip-basket or air-lift and fish were taken as quickly as possible from those structures. The fish collection system at Rock Island Dam is not readily accessible for “real-time” collection; therefore, fish were examined after they had been transferred to the smolt monitoring facility. Fish could have been in the Rock Island system for up to 24 hours before being examined for GBD.

Prior to collecting any fish, all equipment was set up and checked to be sure it was functioning properly. Each site had five 5-gal plastic buckets - three buckets for holding fish and two for irrigating fish gills during examination. Two holding buckets contained MS-222, buffered with bicarbonate, at concentrations of 80 and 30 mg/L made with water from the site of fish collection. As fish were collected they were put in the 30 mg/L bucket and taken to the examination station and then transferred one at a time, just prior to examination, to the 80 mg/L bucket. The third holding bucket was the recovery bucket and contained clean water (without anesthetic) with an air stone vigorously aerating the water and a lid to insure that fish did not jump out after recovering from the anesthetic. Two buckets were used to irrigate the fish gills during GBD examination. A valve regulated the flow of water (containing buffered 30 mg/L MS-222) down a length of surgical tubing. The tubing released water into the examination tray. The water level in the tray was such that it flowed into the fish's mouth and over the gills. A catch basin under the examination tray directed the water into the fifth bucket on the floor. During the course of the sampling season, staff at each sampling site modified the procedures to make use of the system in which they worked. For example, at several sites fish were put into existing recovery systems that shunted fish to the appropriate raceways after examinations. Some workers found that the concentration of anesthetic in the water irrigating the fish gills could be reduced or eliminated without problem. Because these modifications were in the best interest of the fish, they were authorized.

One hundred fish per species were examined each sampling day. Species sampled were spring/summer or fall chinook salmon and steelhead ***O. mykiss.*** Sampling was done without regard to fin clips (i.e., no distinction was made between hatchery and wild fish); however, adipose clips were noted. Only as many fish as could be examined within 15 minutes of capturing the first fish were collected at one time. Exceptions were at John Day Dam and Bonneville Dam where samples were collected once each hour, and at Rock Island Dam where all fish were collected during the 24 hours prior to sampling.

After a fish was fully anesthetized, we recorded the fish's forklength, and placed it on the examination tray with the left side of the fish up. Using a dissecting microscope (4 - 40x), the biologist examined the dorsal, caudal, and anal fins and the eye and noted the presence of any gas bubbles. Based on the absence or presence of bubbles, each fin was rated on the following scale:

0 = no bubbles

1 = 1 - 5% of fin was covered with bubbles

2 = 6 - 25% of fin was covered with bubbles

3 = 26 - 5 0 % of tin was covered with bubbles

4 = greater than 50% of fin was covered with bubbles.

We then placed a micrometer on the side of the fish, parallel to the lateral line. Micrometers are narrow, flexible, clear plastic strips with unit-less hatch-marks, spaced about every 0.5 mm along its length. Several micrometers of various lengths were available and we used one that was at least as long as the fish's lateral line. Again using a dissecting microscope, we examined the lateral line for bubbles and counted the number of micrometer units that were occluded with bubbles. Using the same micrometer, we measured the length of the lateral line from the end of the caudal peduncle in a straight line to the operculum. If there were no bubbles in the lateral line, its length was not measured. We worked as quickly as possible; fish were put in the recovery bucket as soon as possible. After all fish in the batch had been examined, they were returned to the collection system.

All measurements were recorded in the appropriate place in the data sheet. After all fish were examined, or at intervals through the day, the data were transferred to the computer data file. After all data were entered into the computer file, we proofed the computer file against the written data sheet and corrected any erroneous entries. The computer file was transferred electronically to the Fish Passage Center.

Results

Snake River

About 600 to 1,000 spring chinook salmon were sampled at each of the three Snake River dams from mid April through July (Table 1). Of all spring chinook salmon examined at each site, between 1.5% and 5.4% had signs of GBD (Table 1). On a daily basis, the prevalence of fish with any signs was usually less than 10% for the lateral line and fins and eyes. However, at

Lower Monumental Dam prevalence in the fins and eyes exceeded 14% on 3 days and peaked at 23% on June 6 (Figs. 1, 2, & 3). Although the number of spring chinook salmon with signs and the number of days when any signs were seen were low, it appeared that both increased when comparing Lower Granite to Little Goose to Lower Monumental (Figs. 1, 2, & 3). Spring chinook salmon with fin and eye bubbles had a maximum rating of 1.25 of 4 (Table I). Maximum percent occlusion of the lateral line was less than 3.0% at Lower Granite and Lower Monumental dams. At Little Goose Dam 9 of 916 spring chinook had lateral line bubbles. Five of thcsc fish had over 22% occlusion with a maximum of 53.2%.

About 1,600 to 1,750 steelhead were sampled at each of the three Snake River dams from mid April through July (Table 1). Of all steelhead examined at each site, between 3.5% and 10% had signs of GBD (Table 1). On a daily basis, the prevalence of fish with any signs was usually less than 10%. However, at Littlc Goose Dam fin and eye prevalence was 40% the first day of sampling (Fig. 2) and at Lower Monumental Dam prevalence in the fins and eyes exceed 10% on 14 days and peaked at 34% on June 21 (Figs. 1, 2, & 3). The number of steelhead with signs and the number of days when any signs were seen were low at Lower Granite and Little Goose dams, but increased at Lower Monumental Dam (Figs. 1, 2, & 3). Maximum percent occlusion of the lateral line was 3.0% or less at Lower Granite and Lower Monumental dams. Steelhead with tin and eye bubbles had a maximum rating of 1.75 out of 4 (Table 1). At Little Goose Dam 21 of 1752 steelhead had lateral line bubbles. All of these fish had a rating of 2.7% or below except two, with a maximum of 62.5%.

Columbia River

Between 900 to 2050 spring chinook salmon were examined at each of the four Columbia River dams (Table 1). In addition, between 1200 to 2900 fall chinook salmon were examined at each dam; however, fewer than 0.4% (20 of 4,629) of the fall chinook salmon at the lower Columbia River dams (McNary, John Day, and Bonneville) had any signs and those signs were very minor. At Rock Island Dam prevalence of bubbles in fins or eyes of fall chinook salmon was 7% (Table 1; daily prevalence not shown).

The proportion of spring chinook salmon with any sign of GBD was low at McNary Dam (1.2%) but prevalence of signs increased in fish examined at dams further down the Columbia River -- increasing to 5.5% at John Day Dam and 9.9% at Bonneville Dam (Figs. 5, 6, 7 and Table 1). On a daily basis, the prevalence of bubbles in the fins and eyes in spring chinook salmon at the lower Columbia River dams exceeded 10% on only two occasions -- John Day Dam on May 6 and June 3 Lateral line occlusion exceeded 10% just twice -- at John Day Dam on May 25 and June 3 (Fig. 6). The maximum percent occlusion of the lateral line in spring and fall chinook salmon examined at the lower Columbia River dams was 4.1% and the maximum fin bubble rating was 0.75.

The prevalence of signs in spring chinook salmon at Rock Island Dam was very different from that seen at the lower Columbia River dams (Table 1 and Fig. 4). Prevalence in the fins, eyes and the lateral line, as well as percent occlusion of the lateral line, appeared to be higher than that seen at lower Columbia River dams until the last few days of the sampling season (after July 1). Fin and eye prevalence was generally higher than 10% especially in the early sampling period (April 26 to May 6) when all days were above 29% and the highest prevalence was 67% (Fig. 4). Lateral line prevalence was also high during the first few weeks of sampling with a peak of 98% on April 29 and May 1. For the season, 49.4% of the spring chinook salmon showed signs of GBD and the maximum occlusion in the lateral line was 74.4% (Fig. 4).

Between 900 and 1200 steelhead were sampled at each lower Columbia River dam; steelhead were not sampled at Rock Island Dam. The proportion of steelhead with any sign of GBD was low at McNary Dam (3.1%) but prevalence of signs increased in fish examined at downstream dams -- increasing to 9 8% at John Day Dam and 9.9% at Bonneville Darn (Figs. 5, 6, 7 and Table 1). At McNary Dam prevalence in the fins and eyes exceeded 10% on 5 days later in the season (after June 1) with a peak of 33% on June 8 (n=10). Of all steelhead examined during the season, only one had a lateral line occluded with bubbles (Fig. 5). While the prevalence of signs in fish increased at downstream dams, the severity remained low at all three dams -- the maximum percent occlusion of the lateral line was 2.3% and the maximum fin rating was 2.0 (Table 1).

Discussion

The Snake and Columbia River basins experienced very high spring runoff which resulted in uncontrolled spills and high TDG levels in the mainstream rivers. In addition, TDG levels at the tailrace of Lower Granite Dam were high early in the season due to construction of an experimental bypass system. TDG levels were also high in the tailraces of Ice Harbor and John Day dams. River levels at all monitoring sites exceeded TDG guidelines (120%) for 8 of the first 10 weeks of the season. Because of these high TDG levels sampling was done every other day at all sites except Rock Island Dam. These high TDG levels resulted in an increase in the prevalence and severity of signs of GBD compared to the 1995 sampling season. This was true for spring chinook salmon and steelhead at all sites. However, river levels of TDG were below 120% when the fall chinook salmon migration began and these fish showed very low incidence of GBD, as they had in 1995. For the 1996 season prevalence of GBD signs in the fins, eyes, and lateral line of spring chinook salmon and steelhead sampled at the Snake and Columbia river dams varied greatly. Overall the incidence of GBD was low, 10% or less, except for spring chinook salmon at Rock Island Dam. In the Snake River only 3.7% of all spring chinook salmon and 5.9% of steelhead sampled had signs of GBD. At the lower Columbia River dams, 2.3% of spring chinook salmon and 7.3% of steelhead sampled had signs of GBD. There were certain days when fish at individual sample sites showed increased prevalence of signs in the fins and eyes or lateral line. For example, on June 3 at John Day Dam steelhead had a high prevalence in the lateral line (31%) and fins and eyes (40%). Also, spring chinook salmon at Lower Monumental Dam showed increased prevalence in the fins and eyes (but not lateral line) for 3 days in early June. However, in both examples the severity of GBD signs in most of these fish was minor.

There was higher prevalence of GBD signs observed in steelhead compared to spring chinook salmon at all the dams where both were sampled. On the Snake River the difference was most dramatic at Lower Monumental Dam where prevalence in the fins and eyes was below 10% in spring chinook and above 10% in the steelhead for most of the season. However, these steelhead had a low prevalence of lateral line bubbles. On the lower Columbia River both John Day and Bonneville dams had a marked difference in prevalence At Bonneville Dam prevalence never exceed 10% in the fins and eyes of spring chinook salmon but was over 10% in the steelhead on 6 days. The combined prevalence (fins and eyes, lateral line) of GBD signs for the season at Bonneville Dam was 0.8% for spring chinook salmon and 9.9% for steelhead. At John Day Dam the difference between the combined prevalence was 5.5% for spring chinook salmon and 9.8% for steelhead. On a daily basis the differences in prevalence in the fins and eyes or lateral line is not as clear but overall it appears that steelhead had a higher prevalence of signs, especially in the fins and eyes, than the spring chinook salmon. Once again, while the prevalence of signs was high, the severity was low. For example, while total prevalence for the steelhead was 9.9%, the maximum percent occlusion of the lateral line was only 0.8%.

While signs of GBD were low at the Snake River dams and the lower Columbia River dams, prevalence of bubbles in the lateral line or fins and eyes of fish examined at Rock Island Dam was high throughout the season. Combined prevalence of GBD signs was 49.4%, compared to 2.3% for the lower Columbia River dams. Unlike all other sample sites, prevalence of signs in fish examined at Rock Island Dam was higher in the lateral line than in the fins and eyes. The severity of signs at Rock Island Dam was high with a maximum occlusion by bubbles in the lateral line of 74.4%. The maximum fin bubbles rating of 2.25 was also the highest of all sites. Combined prevalence of signs in spring chinook salmon and steelhead increased in fish sampled downriver from Lower Granite to Little Goose to Lower Monumental dams. Severity of signs did not show a similar increase in downriver samples but was highest at Little Goose Dam. This may be related to the high TDG levels caused by spills at Lower Granite Dam. While GBD signs increased in fish downstream dams in the Snake River, McNary Dam had the lowest prevalence and severity rating of all sample sites on the Columbia River. This is surprising given the increasing incidence at Snake River dams and the high incidence at Rock Island Dam. While the prevalence in the steelhead did increase at John Day and Bonneville dams (about 9.9%) the severity of signs at these sites remained low While John Day Dam reported high TDG levels during the spill. the prevalence and severity of signs at Bonneville Dam went down in the spring chinook and showed a relatively small increase in the steelhead.

In general, results of the 1996 GBD monitoring program help verify that the protocol is sensitive to changes in GBD caused by increases in TDG in the river. That is, under controlled spill in 1995 when TDG was maintained near the allowable 120% level, there were fewer signs of GBD than in 1996 when uncontrolled spill drove TDG to levels consistently higher than 120%.

Table 1. Prevalence and severity of gas bubble trama in juvenile spring chinook salmon and steelhead sampled at collection facilities located at dams on the Snake and Columbia Rivers in 1996 during downstream migration.

Site[1]	Species[2]	Total Fish Sampled	Total Fish with Any Signs	Prevalence[3]	Max. % Occlusion of Lateral Line [4]	Max. Fin Bubbles[5]
LGR	SPCH	621	9	1.5 %	1.3	0.25
	STHD	1621	56	3.5 %	3.0	1.00
LGS	SPCH	916	30	3.3 %	53.2	1.25
	STHD	1752	76	4.3 %	62.5	1.75
LMN	SPCH	1095	59	5.4 %	2.9	1.00
	STHD	1663	166	10.0%	1.9	0.25
MCN	SPCH	1198	15	1.2 %	0.0	0.50
	STHD	1212	38	3.1 %	1.9	2.00
	FACH	1451	1	0.1 %	0.0	0.25
JDD	SPCH	929	51	5.5 %	1.3	0.75
	STHD	931	91	9.8 %	0.8	1.00
	FACH	1625	10	0.6 %	2.6	0.25
BON	SPCH	1096	9	0.8 %	4.1	0.50
	STHD	1039	103	9.9 %	2.3	1.75
	FACH	1553	9	0.6 %	2.6	0.25
RIS	SPCH	2859	1412	49.4 %	74.4	2.25
	FACH	2050	144	7.0 %	2.0	1.0

l-Bon = Bonneville Dam JDD = John Day Dam RIS = Rock Island Dam MCN = McNary Dam LMN = Lower Monumental Dam LGS = Little Goose Dam LGR = Lower Granite Dam

2-SPCH = spring chinook salmon FACH = fall chinook salmon STHD = steelhead

3-Prevalence represents the percent of all fish sampled with any bubbles in their fins or lateral line

4-% Occlusion of lateral line = (Bubble Units \ Lateral Line Units) • 100

5-Fin Bubbles represents the sum of fin code values divided by three. Maximum value = 3.0
Fin rating: 0 = no bubbles; 1 = 1-5%; 2 = 6-25%; 3 = 26-50%; 4= >50% of fin occluded.

Lower Granite Dam
1996

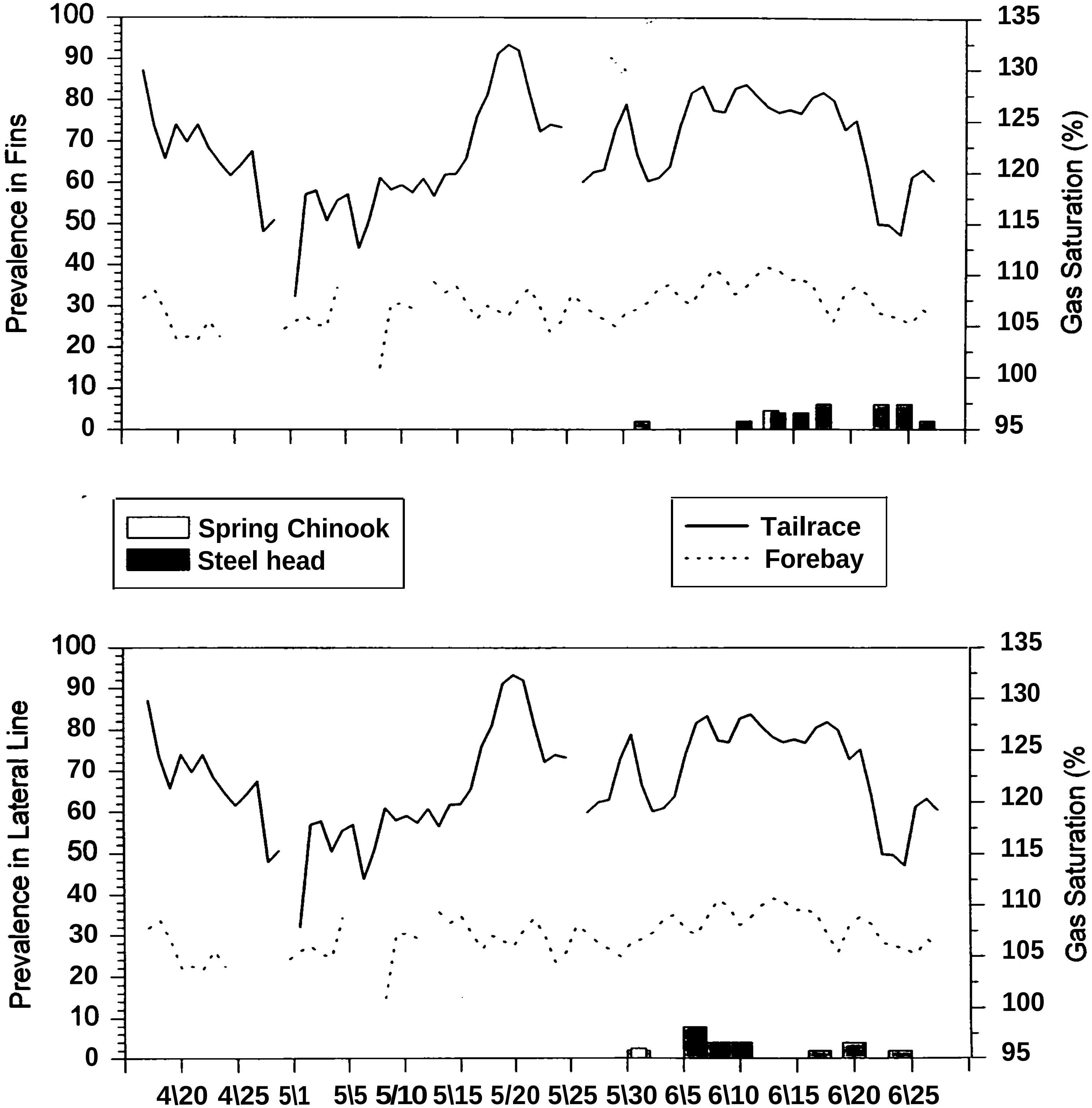

Figure 1. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and steelhead and gas saturation in the forebay and tailrace of Lower Granite Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Sample sizes vary by day (Appendix 1 and 2).

Little Goose Dam
1996

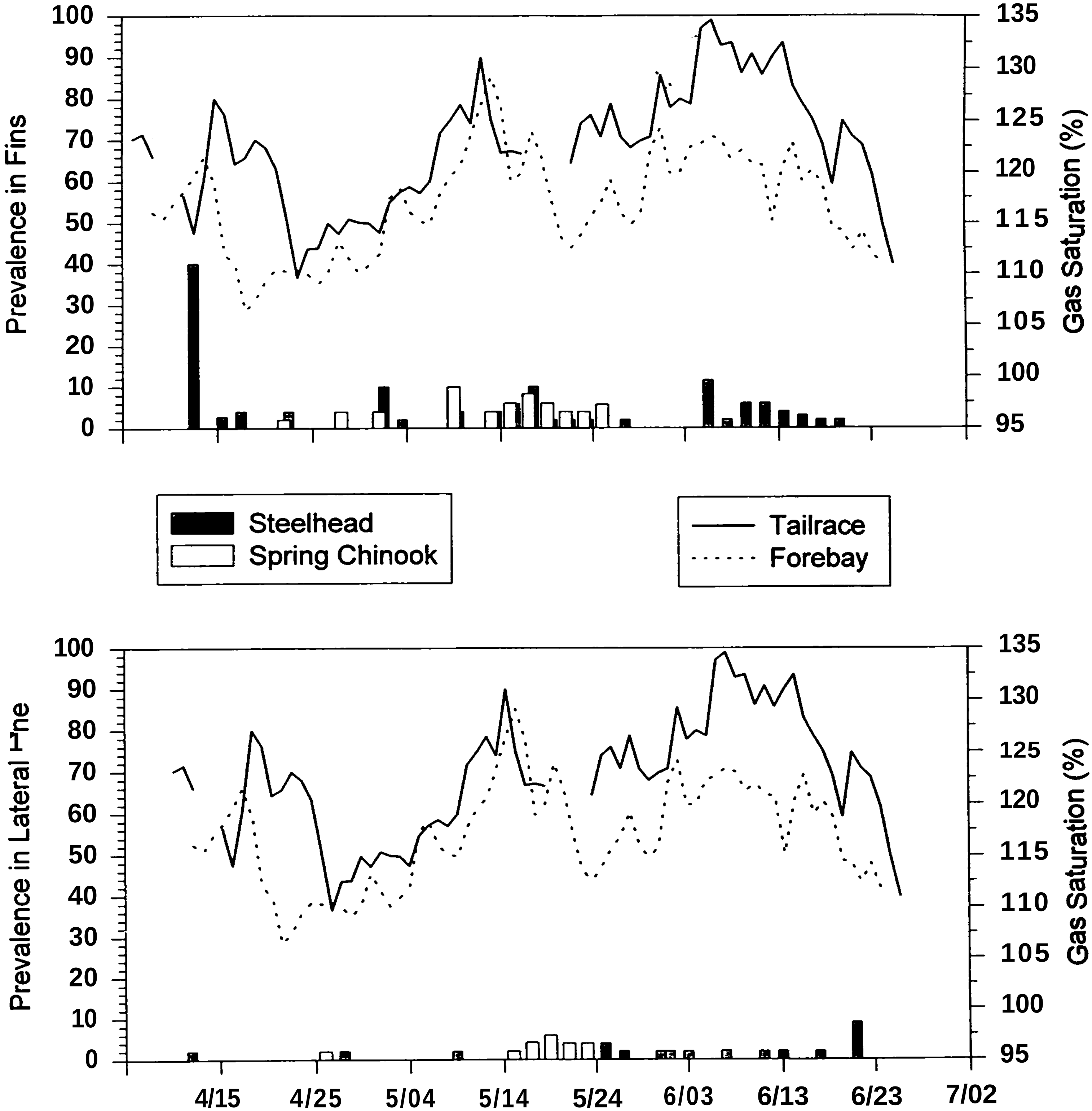

Figure 2. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and steelhead and gas saturation in the forebay and tailrace of Little Goose Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Sample sizes vary by day (Appendix 3 and 4).

Lower Monumental Dam 1996

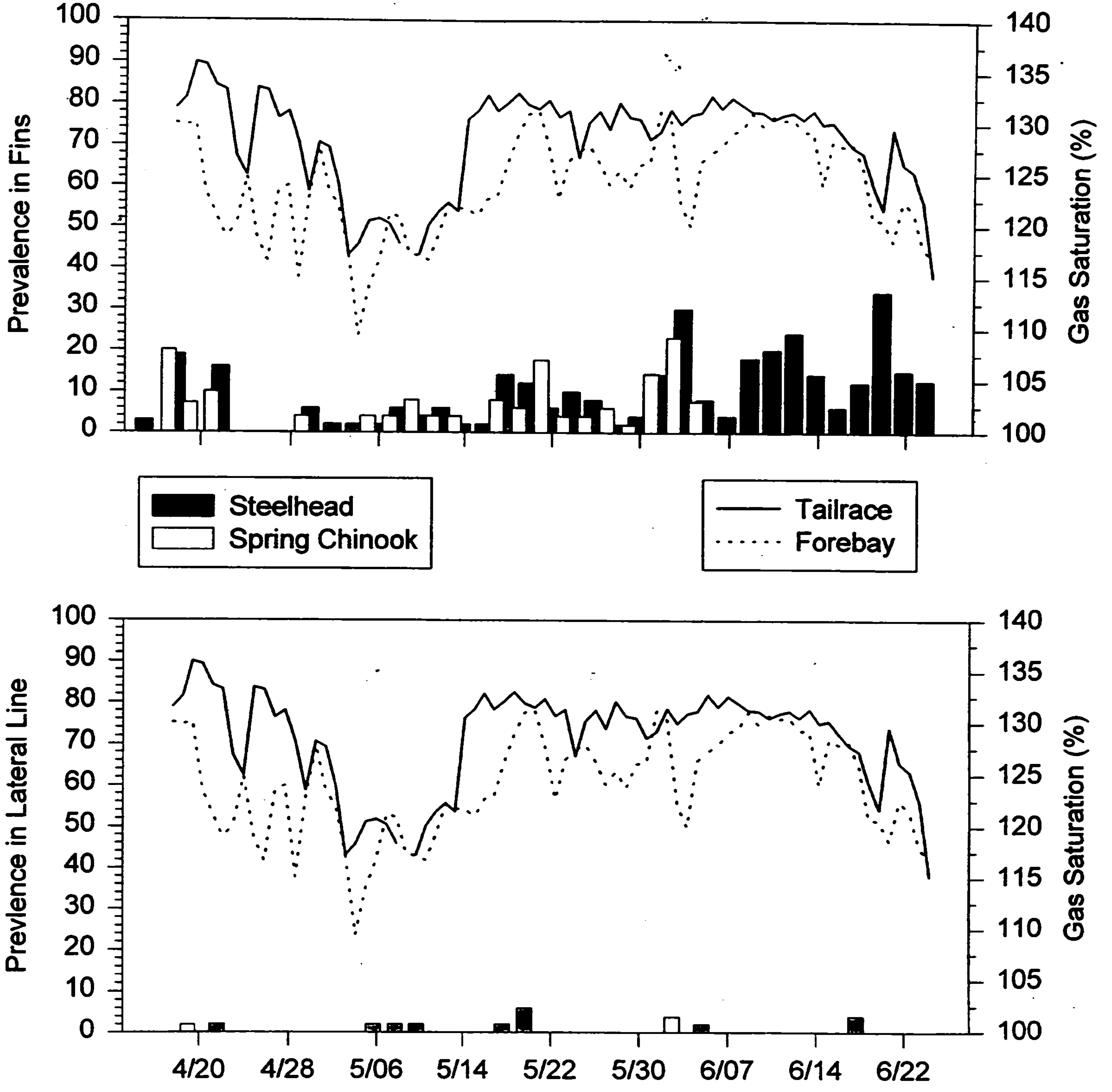

Figure 3. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and steelhead and gas saturation in the forebay and tailrace of Lower Monumental Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Sample sizes vary by day (Appendix 5 and 6).

Rock Island Dam
1996

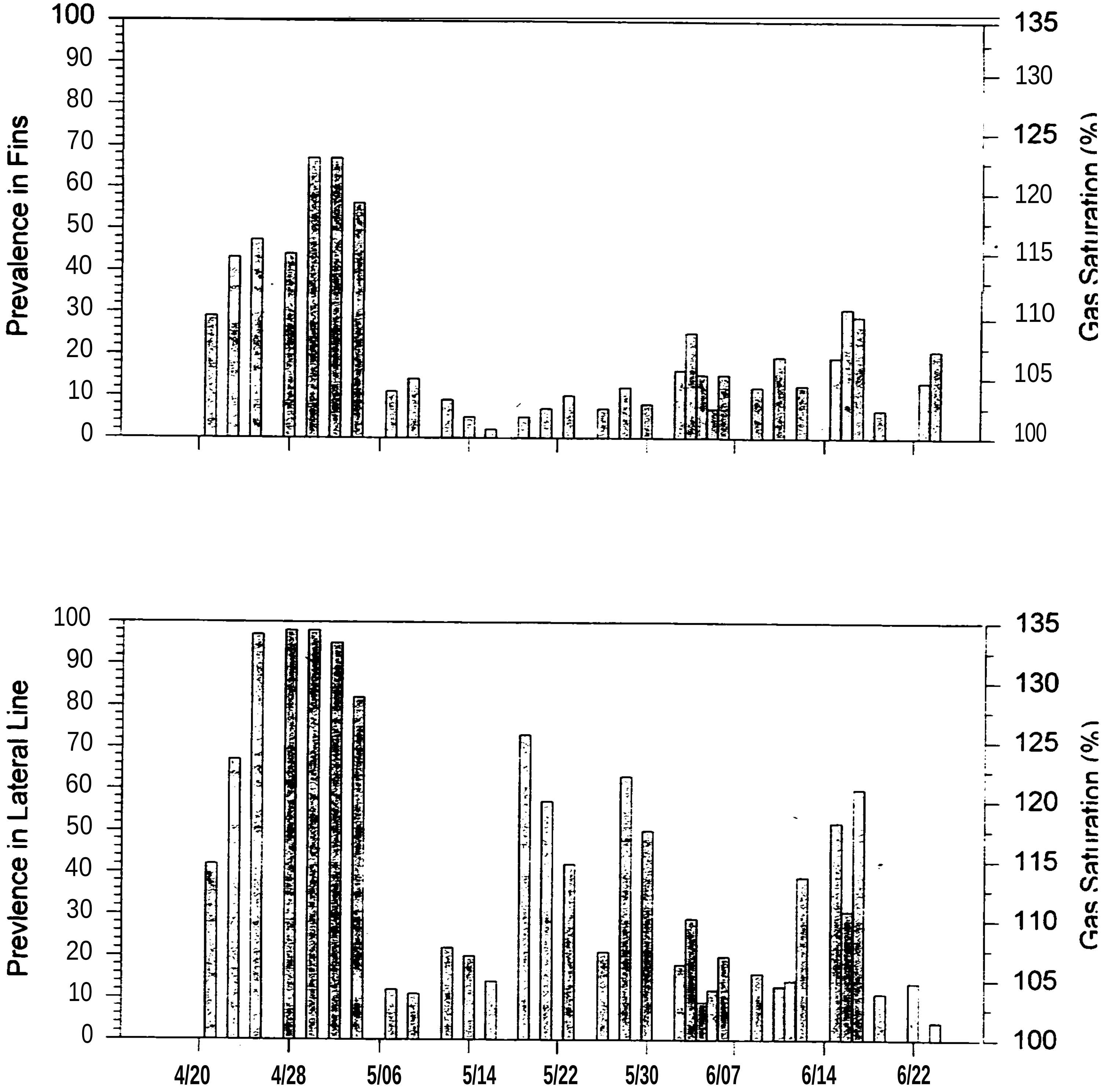

Figure 4. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and gas saturation in the forebay and tailrace of Rock Island Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Sample sizes vary by day (Appendix 7).

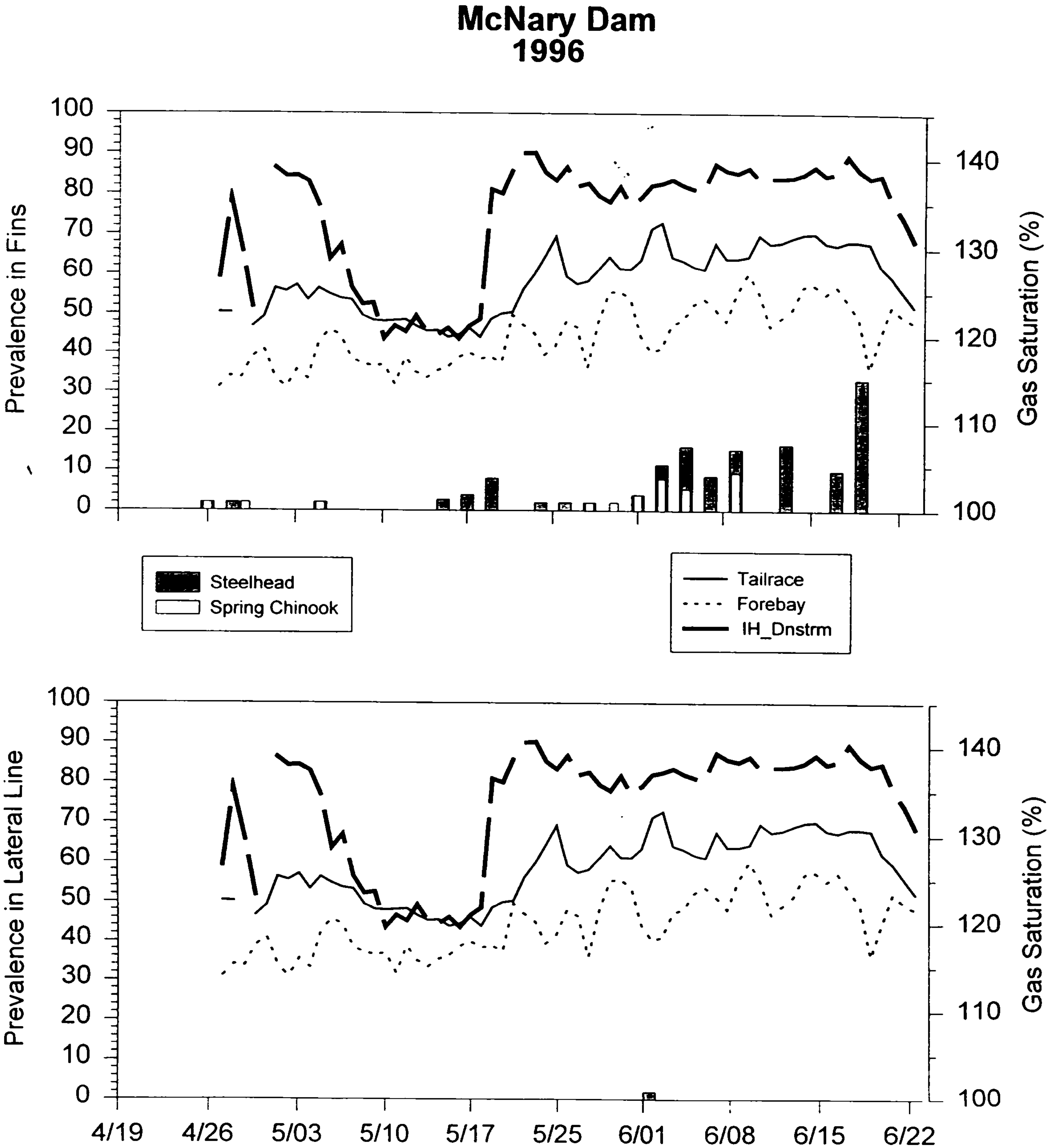

Figure 5. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and steelhead sampled at McNary Dam and gas saturation downstream of Ice Harbor Dam (IH_Dnstrm) and in the forebay and tailrace of McNary Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Sample sizes vary by day (Appendix 8 and 9).

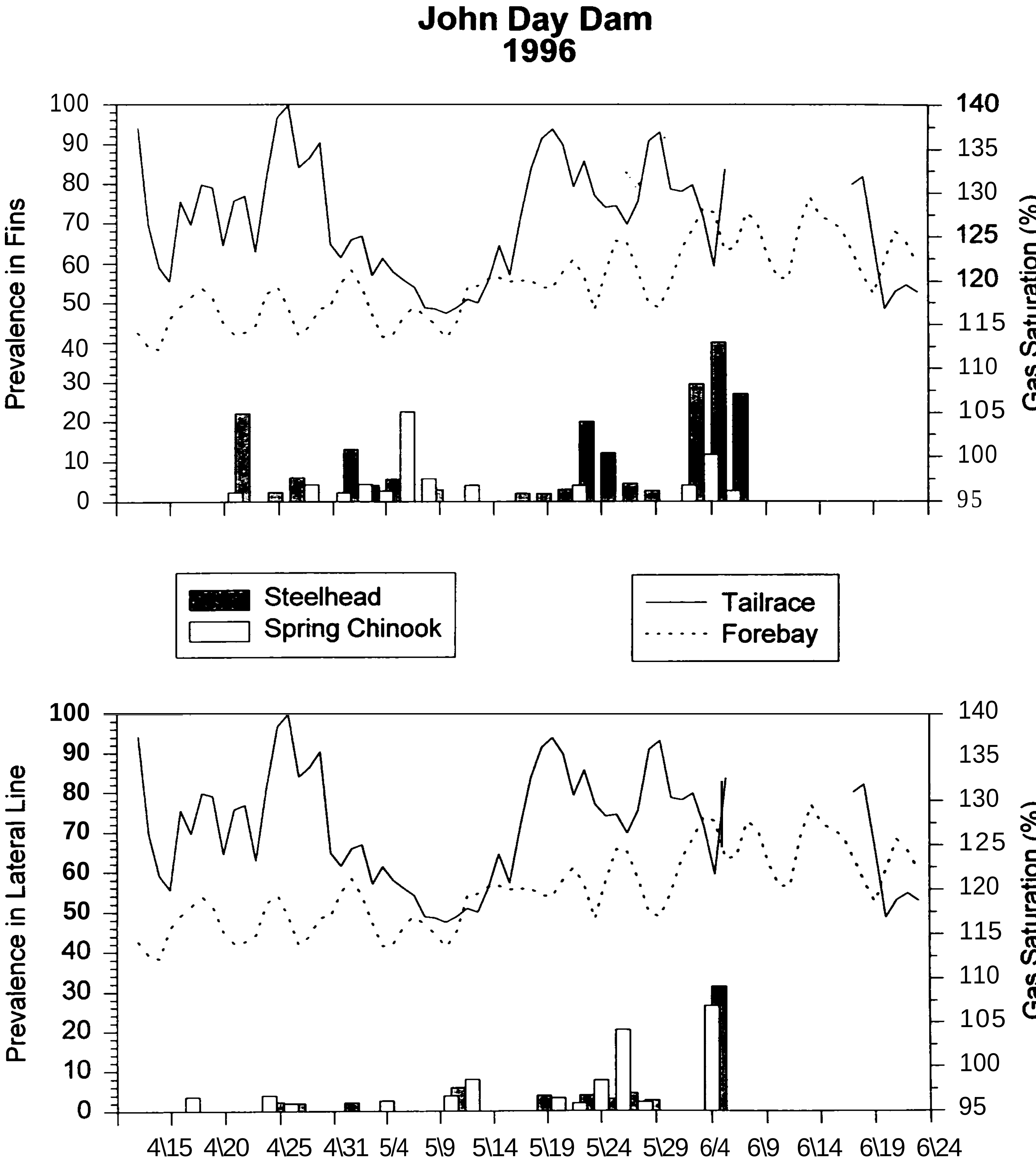

Figure 6. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and steelhead and gas saturation in the forebay and tailrace of John Day Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Sample sizes vary by day (Appendix 12 and 11).

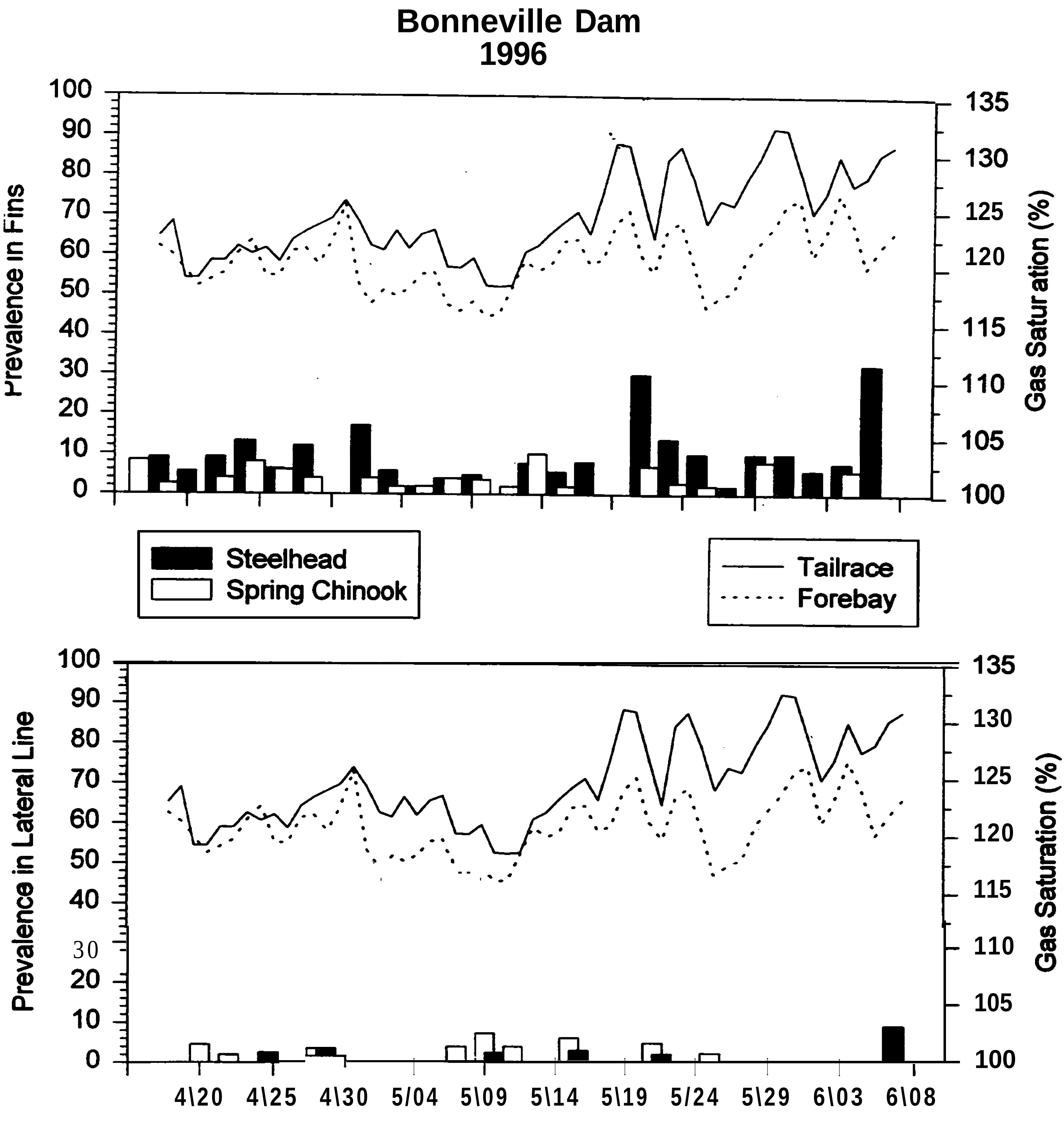

Figure 7. Prevalence (% positive) of bubbles in fins and eyes (top) and lateral line (bottom) of spring chinook salmon and steelhead and gas saturation in the forebay and tailrace of Bonneville Dam. The width of the graph bars in no way represents sample size, prevalence, or degree of severity. Tailrace TDG % taken at Warrendale, OR, four miles down river from Bonneville Dam. Sample sizes vary by day (Appendix 12 and 13).

Chapter 3

Progression and Severity of Gas Bubble Trauma in Juvenile Chinook Salmon and Development of Non-lethal Methods for Trauma Assessment

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Introduction

Until recently, dissolved gas supersaturation (DGS) and its effects on salmonids in the Columbia River system were considered problems that had been solved, largely because an extensive research effort during the mid 1960's-1970's (Ebel et al. 1975; Ebel 1979; Weitkamp and Katz 1980) led to modifications in the physical structure and operation of most dams. However, because of the listing of several Snake River salmonid stocks under the Endangered Species Act and the use of increasing amounts of spill for fish passage, there is now renewed concern about the effects of DGS, particularly sublethal or indirect effects. Advocates for the use of spill argue that it provides a quick and safe journey past dams and thus increases overall survival relative to, for example, turbine passage. However, high spills may also increase levels of DGS to the point where mortality due to gas bubble trauma (GBT) in outmigrating juvenile salmonids may negate any presumed benefits associated with spill.

To help assess the efficacy of spill as a management tool, a program was initiated in 1994 to monitor juvenile salmonids for signs of GBT as they traveled to the ocean. Basically, the program consisted of examining fish collected at dams on the Columbia and Snake rivers for signs of GBT It was thought that such monitoring would allow continuous assessment of the prevalence and severity of GBT during the outmigration and such information could serve as a basis for management decisions concerning spill. The signs of GBT monitored included bubbles in the lateral line, fins, external body surface, and gills.

One of the problems inherent in such a monitoring program is trying to quantify and ascribe some ecological significance to the severity of GBT signs observed in fish. Although there are numerous descriptions of GBT signs in salmonids and other fishes (e.g., Dawley and Ebel 1975; Nebeker and Brett 1976; Nebeker et al. 1980; Weitkamp and Katz 1980; Lutz 1995) most such accounts describe signs in moribund or dead fish. Such descriptions, though useful, are really ecologically "too late" when attempting to evaluate signs at a sub-lethal level. There are some ancillary descriptions of the progression of GBT which do indicate the order in which signs usually appear (Meekin and Turner 1974; Dawley and Ebel 1975; Schiewe and Weber 1975). For example, at certain gas levels, it is well established that bubbles first appear in the lateral line, followed by subcutaneous blisters on the body surface or fins. Unfortunately, these accounts often lack explicit detail, do not attempt to quantify the severity of signs, or are at a histological level. Although the histological descriptions of GBT (Machado et al. 1987; Smith 1988; Machado et al. 1989) are quite detailed, they are of little practical use to a monitoring program where the emphasis is on a rapid, non-lethal assessment of GBT. Despite the large amount of research on GBT in fishes, which has primarily examined acute mortality, the development of methods to provide a rapid, quantitative description of the signs of GBT is still lacking. In addition, and perhaps more importantly, the relation of sub-lethal signs to potential mortality is necessary for a full understanding of the effects of GBT on fishes.

Our overall goal in this work was to determine an optimal method for assessing GBT in juvenile salmonids, one that is rapid, non-lethal, and examines relevant signs at a sub-lethal level By implementing such a method into the GBT monitoring program, we hoped to place the program on a solid biological foundation and make it highly efficacious To achieve this goal, we had two objectives. First, we assessed the progression and quantified the severity of signs of GBT in juvenile salmonids exposed to different levels of total dissolved gas (TDG) and temperatures. Next, we evaluated prevalence, severity, and individual variation of GBT signs in an attempt to relate them to the likelihood of mortality. This report describes the results obtained during our second year of study

Methods

Test Fish

Spring chinook salmon ***(Oncorhynchus tshawytscha;*** age 1+) were used for all trials; average fork length and mass differed among the trials (Table 1). All fish were from the Little White Salmon National Fish Hatchery, Cook, Washington. The fish were transferred to our laboratory and reared outside in 1400-L, flow-through circular fiberglass tanks receiving 6-8°C well water. About two weeks before trials began, groups of fish were transferred indoors and placed in several 228-L tanks receiving well water heated to either 12 or 15°C. Excess dissolved gas generated by heating the water was dissipated by a packed column. Fish were fed ***ad libitum*** once daily with commercial feed and held under natural photoperiod.

Table 1 .--Mean (and SE) fork lengths and weights of juvenile spring chinook salmon used in GBT progression experiments during 1996.

Trial	N	fork length (mm)	weight (g)
130%,12°C	88	141 9(1.21)	29.8 (0.83)
130%, 15°C	88	148.4 (0.89)	34.5 (0.69)
120%, 12°C	97	148.7 (1.19)	34.8 (0.93)
110%, 12°C	114	155.0 (1.00)	40.0 (0.78)

Experimental System

Supersaturated water was generated by a combination of heating and pumping well water under pressure and injecting atmospheric air. Water at 7°C flowed into a 114-L, circular fiberglass tank where it was then pumped under 38 psi into a single-pass 50-kW heater. A 1-Hp air compressor injected atmospheric air at 60 psi directly into the water line entering the pump; a flow meter controlled the rate of air injected and hence the level of TDG we achieved. After leaving the pump, water was heated to 12 or 15 °C before flowing into a 23-m-long coil of 1.3-cm-diameter garden hose to allow some time under pressure and to minimize turbulence before water entered a 111-L PVC retention tank. The retention tank vented excess bubbles and maintained a constant head pressure as supersaturated water flowed by gravity (7.0 L/min) into three 228-L flow-through circular holding tanks

Experimental procedure

We assessed the progression of gas bubble trauma in juvenile salmon at TDG levels of 130%, 120% and 110% in separate experiments. We conducted one trial at each TDG level at 12°C, and an additional trial at 130% TDG at 15°C. For each trial, we stocked 75 juvenile salmon into each of the three tanks receiving supersaturated water. The water volume in each tank was 113-L and was 28 cm deep to minimize depth compensation. We used fish in two tanks to monitor the progression of GBT and fish in the third tank to monitor mortality. A fourth group of fish was held in a tank receiving normally saturated water and served as controls. During the trials, our test fish were experiencing an epizootic of bacterial kidney disease, which was beyond our control. To account for this, we removed kidneys from selected groups of fish to determine their level of infection During a trial, we used a TDG meter (Common Sensing, Inc., Clark Fork, ID) and a Weiss saturometer to record water quality variables in treatment and control tanks. We monitored barometric pressure, water temperature, total dissolved gas (P_{tot}), barometric pressure minus P_{tot} (delta P), and percent total saturation.

Sampling and Examination

After stocking, we sampled 4 fish from each treatment tank at selected time intervals to record the progression of GBT. We sampled fish every hour at 130% and every 24 h at 110%. At 120%, we sampled fish every 12 h during the first day, every 6 h during the second day, and every 2 h up through 60 h. Sample periods were based on preliminary experiments and published information on GBT signs and times to mortality. At the beginning and end of each trial, we sampled 10 control fish.

Fish were sampled by rapidly netting them from their tank and placing them in a lethal dose of MS-222 (200 mg/L) buffered to a pH of 7 with an equal amount of sodium bicarbonate. Anaesthetic was prepared in normally saturated water for control fish and supersaturated water for treatment fish. Fish were serially removed from the anaesthetic, weighed and measured, and placed left side up on a moist paper towel. First, we scanned for gas bubbles within the lateral line using dissecting scopes (Leica Wild M3 Z) with 8-40x zoom magnification and fiber optic illumination (Leica Lux 1000). We measured the percent of the length of the lateral that was occluded with bubbles using a hand-held micrometer. The micrometer was divided into arbitrary units of about 0.5 mm and was used to measure the length of the lateral line and the total length of gas bubbles within the lateral line, thus providing the data necessary to derive percent occlusion. We then estimated the percent surface area of each unpaired fin covered by bubbles and ranked severity as: 0 = no bubbles present; 1 = l-5% covered; 2 = 6-25% covered; 3 = 26-

50% covered; and 4 = > 50% covered. We completed the external examination by recording bubbles as present or absent in the eye, opercle, body surface, mouth, and paired fins.

For examination of the gills, we used a new procedure for excising all the gill arches from the left side of the fish that allowed us to obtain clean, unobstructed views of any individual arch. First, we clamped off the ventral aorta leading to the branchial arteries by placing a hemostat on the isthmus of the fish between the opercles. This procedure allowed us to remove the opercle and gill arches with minimal bleeding. The four gill arches were then placed concave-side down on a glass slide, covered with a few drops of anaesthetic solution and examined under the dissecting microscope at 8-40x We counted the number of gill filaments with intravascular bubbles in each arch. After this, we used a single-edged razor blade and blunt probe to remove filaments from the first (and largest) gill arch only, spread them in a single layer over a glass slide, covered them with anesthetic solution, and again counted the number of filaments with intravascular bubbles. For this count, however, we used compound microscopes with 40-100x magnification Several personnel were used to conduct the examinations, which usually required about 20 minutes to complete a sample of 8 fish. Experimental trials ended when virtually all fish had been sampled from the two sample tanks.

Data Analysis

Mortality was plotted as a cumulative percentage over time. We fitted a curve through the points by eye and estimated the time to 50% mortality (i.e., the LT_{50}) by extrapolation. Within each time interval, we averaged lateral line and gill data, determined their prevalence and plotted the data over time. Data from the gill arches were examined for each arch separately and for all arches combined. For the fins, we plotted average and maximum severity rankings and prevalence over time using data from all fins combined or data from selected fins.

Results

130% TDG

At 130% TDG, we examined a total of 144 fish during two trials, one trial conducted at 12°C and another at 15 ^{o}C. Each trial lasted 9 h, with cumulative mortality rates being similar between trials (Fig. 1). Mortality was non-existent during the first 5 h of each trial, but then increased steadily to about 50% by the end. The progression of bubbles in the lateral line differed slightly between the two trials (Fig. 2) being generally higher at each time interval for fish tested at 15 ^{o}C For both groups, lateral line occlusion increased in a linear fashion before reaching average peaks of about 20-30% at the end of a trial. Lateral line bubbles were typically rod shaped and often coalesced into long chains. In both trials, the prevalence of lateral line bubbles was high, being at least 75%, and most often 100%, for all sample periods but the first. Although inter-individual variation in lateral line occlusion was relatively low, as evidenced by our standard errors, such variability did tend to increase with time.

Average severity of bubbles in the fins differed slightly between fish in the two trials (Fig. 3). For fish at 12^{o}C, average severity of bubbles in the fins was low for the first 3 h, but then increased gradually before rising to a peak at 9 h. For fish at 15 ^{o}C, average severity rating in the fins was also low during the first 4 h, but then increased, albeit erratically, during the remainder of the trial. For maximum fin severity ratings, the number of fish with no bubbles in their fins (i.e., a rating of 0) decreased during the first 5 h for fish at 12^{o}C, but not for fish at 15°C (Fig. 4). Other maximum fin severity ratings (i.e., ratings l-4) occurred primarily during the last half of the trials. Collectively, fin bubbles increased in prevalence over time in both trials (Fig. 5).

The mean number of gill filaments with bubbles was low during the first 6 h of both trials, before increasing slightly towards the end--a trend that was consistent between the two methods we used to examine gills (Figs. 6 and 7). In addition, there were no definitive trends in the prevalence of bubbles amongst the four arches (Fig. 8). Overall, when using data from all arches combined or from the filaments excised from the first arch, the prevalence of gill bubbles within a sample generally increased over time but was rarely greater than 50% (Fig. 9).

We did occasionally observe other signs of GBT in fish, but these were generally of minor significance relative to those just described. Overall, bubbles found on other parts of the body occurred in the following percentages: pelvic fins, 13% of the fish; pectoral fins, 10%; opercles, 2%; inside the mouth, 1%; and exopthalmia, 8%.

120% TDG

We conducted one trial at 120% TDG and 12°C, examining a total of 88 live fish; the trial lasted 58 h (we monitored mortality through 72 h). Although mortality increased sigmoidally during the trial, it only reached about 43% at the end of the trial (Fig. 10). Average lateral line occlusion increased only slightly during the trial, never exceeding 20% of the lateral line length (Fig. 11). Bubbles in the lateral line were relatively common, with a prevalence of at least 75% for the majority of sample periods (Fig. 12). Inter-individual variability in lateral line occlusion was relatively low throughout the trial.

Average severity rating of bubbles in the fins increased to around 0.3 for the first 42 h, but then increased dramatically to about 1 .0 during the next 12 h before decreasing toward the end of the trial (Fig. 13). There were no evident trends in average severity ratings between the dorsal, caudal, and anal fins. Maximum severity ratings in fins showed that fish with no bubbles (i.e., a rating of 0) were relatively common throughout the trial and that fish with a severity rating of 1 were the most common among fish with fin bubbles (Fig. 14). Fish with a maximum severity rating of 3 first appeared at 30 h whereas fish with a rating of 4 did not appear until 48 h. Overall, the prevalence of fin bubbles was somewhat erratic (Fig. 15) being generally low during the first 42 h but then increasing during the latter half of the trial. On average, prevalence of fin bubbles was about 60%.

The mean number of gill filaments with bubbles was zero for the first 24 h and then increased erratically from 30-50 h before decreasing to very low counts for the remainder of the trial (Fig. 16). Although there were no overtly evident trends in either the number of bubbles (Fig. 16) or prevalence of bubbles amongst individual gill arches (Fig. 17) overall prevalence was erratic and never above 50% (Fig 18).

Again, we did observe other signs of GBT during the trial which occurred in the following percentages: bubbles in the pelvic fins, 11% of the fish; pectoral fins, 7%; opercles, 9%; inside the mouth, 2%; and exopthalmia, 18%.

110% TDG

We examined 104 live fish during one 13 d trial. There were no mortalities due to GBT, but there were several mortalities due to clinical infections of bacterial kidney disease. Lateral line occlusion increased only slightly during the middle of the trial, never exceeding about 3% on average (Fig. 19). Prevalence of bubbles in the lateral line was low to moderate and only approached 50% twice during the trial (Fig. 20).

Fin bubbles showed more definite trends. Average severity of bubbles in the fins increased gradually throughout the trial (Fig. 21). Of the three unpaired fins we examined, only the dorsal fin showed any obvious trend in average severity over time (Fig. 21). Fish with maximum severity ranks of 0 in the fins were common early but became relatively infrequent after day 4 (Fig. 22). There were no obvious trends in maximum severity rating of fins, with a rating of 2 being the most common among fish with fin bubbles (Fig 22). Ratings of 3 and 4 appeared as early as 5 d after the start The prevalence of fin bubbles increased steadily during the first 5 d and maintained levels of at least 60% thereafter (Fig. 23).

The mean number of gill filaments with bubbles was small, rarely affecting more than 1 or 2 filaments. Bubbles within the gill vasculature occurred on only 5 of the 13 sampling days and never affected more than 15% of a sample. Among other signs observed during this trial, exopthalmia was relatively common, occurring in 24% of the fish we sampled. Bubbles found elsewhere on the fish we sampled included: pelvic fins, 10% of the fish; pectoral fins, 7%; opercles, 14%; and inside the mouth, 13%.

Discussion

The work described in this report was a continuation of research started in 1995 and our intent was to pool data from the two years to provide greater insight into our understanding of GBT in juvenile salmonids. Unfortunately, we were unable to validly pool data because all of the trials we conducted this year were done with fish experiencing an epizootic of bacterial kidney disease (BKD). We suspect this outbreak of BKD may have had a profound influence on some aspects of our data, thus precluding our ability to reliably pool data.

The progression and severity of GBT in fish was often different in 1996 than in 1995. The major differences we observed in fish between the years were: at 130% TDG, mortality, mean lateral line occlusion, fin bubble prevalence, mean number of gill filaments with bubbles, and gill filament bubble prevalence were all substantially lower in 1996 than in 1995; at 120% TDG, mean lateral line occlusion, lateral line bubble prevalence, and fin bubble prevalence were also lower in 1996 than in 1995; and at 110% TDG, mean number of fin bubbles and fin bubble prevalence were higher in 1996 than in 1995. Although we cannot say unequivocally, we surmise the effect BKD had on our results may be related to the lethargic behavior exhibited by BKD-infected fish. Because fish activity is one factor that may initiate bubble growth and actually worsen GBT, actively swimming fish may show more severe signs of GBT than lethargic fish for a given DGS exposure. In the future, we hope to minimize the effect of disease epizootics by using a different stock of fish and starting our trials earlier in the spring and summer.

In contrast to the differences in data just described, much of our data exhibited consistent trends and absolute values between the years. For example, lateral line prevalence and mean fin bubble severity were similar for fish exposed to 130% TDG. Also, at 120% TDG, cumulative mortality, mean fin bubble severity, mean number of gill filament bubbles, and gill bubble prevalence were similar between years. And finally, at 110% TDG, there were many similarities--including mean lateral line occlusion, lateral line bubble prevalence, maximum fin severity ratings, mean number of gill filament bubbles, gill filament bubble prevalence, and mortality. Therefore, despite the potential effects that BKD may have had on our results, there was still enough consistency in the data between years to add to our understanding of the development of GBT in juvenile salmonids.

One new aspect of this years research is the method we developed to examine gill arches for intravascular bubbles. A major problem with excising gill arches for examination was the substantial amount of bleeding that occurred upon cutting an arch; such blood significantly reduces the clarity and ease of microscopic examinations. To alleviate this problem, we clamped off the ventral aorta--just "downstream" of the heart--which allowed us to remove all four gill arches with minimal bleeding. We then were able, for the first time, to examine each gill arch for large, intravascular bubbles and thus provide a more detailed description of the progression of

GBT in individual arches. Such information is not only useful to our understanding of GBT, but may also be important to the development of non-lethal methods for examining gills in the field.

Our goal in this research was to provide and validate methods that could be used in a system-wide monitoring program that examines outmigrating smolts for signs of GBT. Despite the problems we had this year with the BKD epizootic, our research is making substantial contributions to a biologically sound monitoring program and ongoing field research. Previously, we discussed the advantages and disadvantages of using the various signs of GBT for smolt monitoring (Mesa et al. in review) and nothing we observed this year has changed our thinking. To reiterate, our data can be useful when trying to assess the severity of DGS exposures in juvenile salmonids in the wild. It is clear, not only from our work but also from past research (Meekin and Turner 1974; Dawley and Ebel 1975; Schiewe and Weber 1975), that GBT in juvenile salmonids is a progressive trauma. That is, many of the signs of GBT become progressively worse over time. In addition, the signs of GBT rarely occur in isolation, even at high levels of TDG. This notion contrasts with the idea that signs of GBT may respond only at certain TDG thresholds and is extremely useful to applying our methods in field situations. If fish in the wild encounter high TDG levels and are exposed for a sufficient time, the progressive nature of GBT indicates that sublethal signs of GBT would be present in a representative sample of fish. In other words, given the progressive nature of GBT, extreme individual variation in susceptibility to GBT, and a rigorous fish sampling program in the field, it should be entirely possible to detect sublethal signs of GBT in fish if, in fact, ***fish are actually experiencing sufficient exposures to DGS.*** By using both prevalence and severity of GBT signs in a sample of fish from a population being exposed to DGS, it should be possible to assess the relative severity of the exposure and provide an “early warning” of potentially lethal exposures. To us, sampling fish in the wild and comparing their GBT signs to those of fish experiencing severe laboratory DGS exposures is a powerful means of assessing the severity of GBT in wild fish, much more so than theoretical computer models whose aim is to predict population mortality due to GBT. Future research in our laboratory will be directed at the progression of GBT in steelhead ***(0. mykiss),*** the potential effects of temperature and activity on GBT development, the rate of disappearance of GBT signs, and the effects of GBT on disease resistance and stress responses in juvenile salmon.

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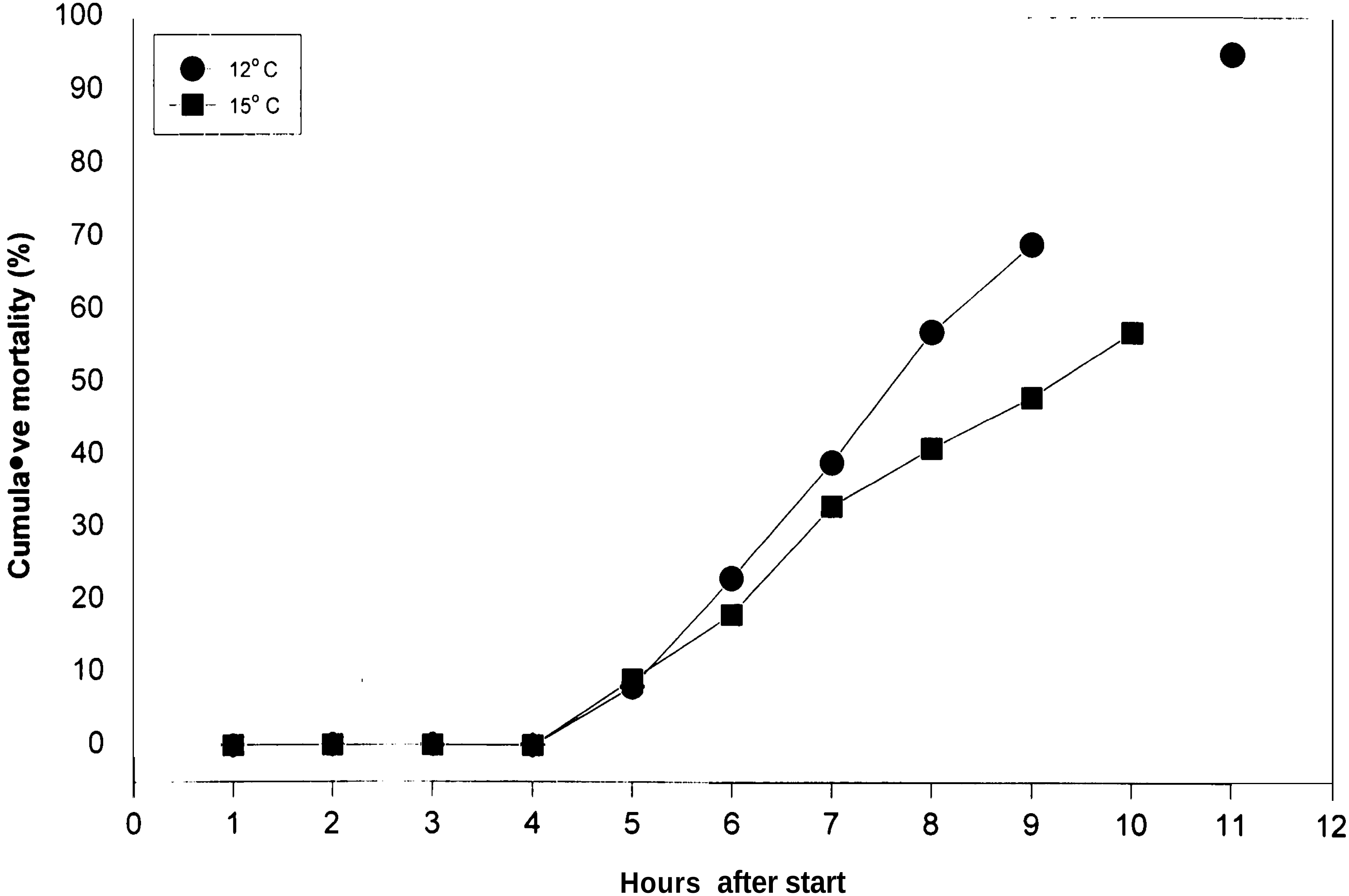

Figure 1 .--Cumulative mortality of juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Total number of fish exposed was 75 in each group.

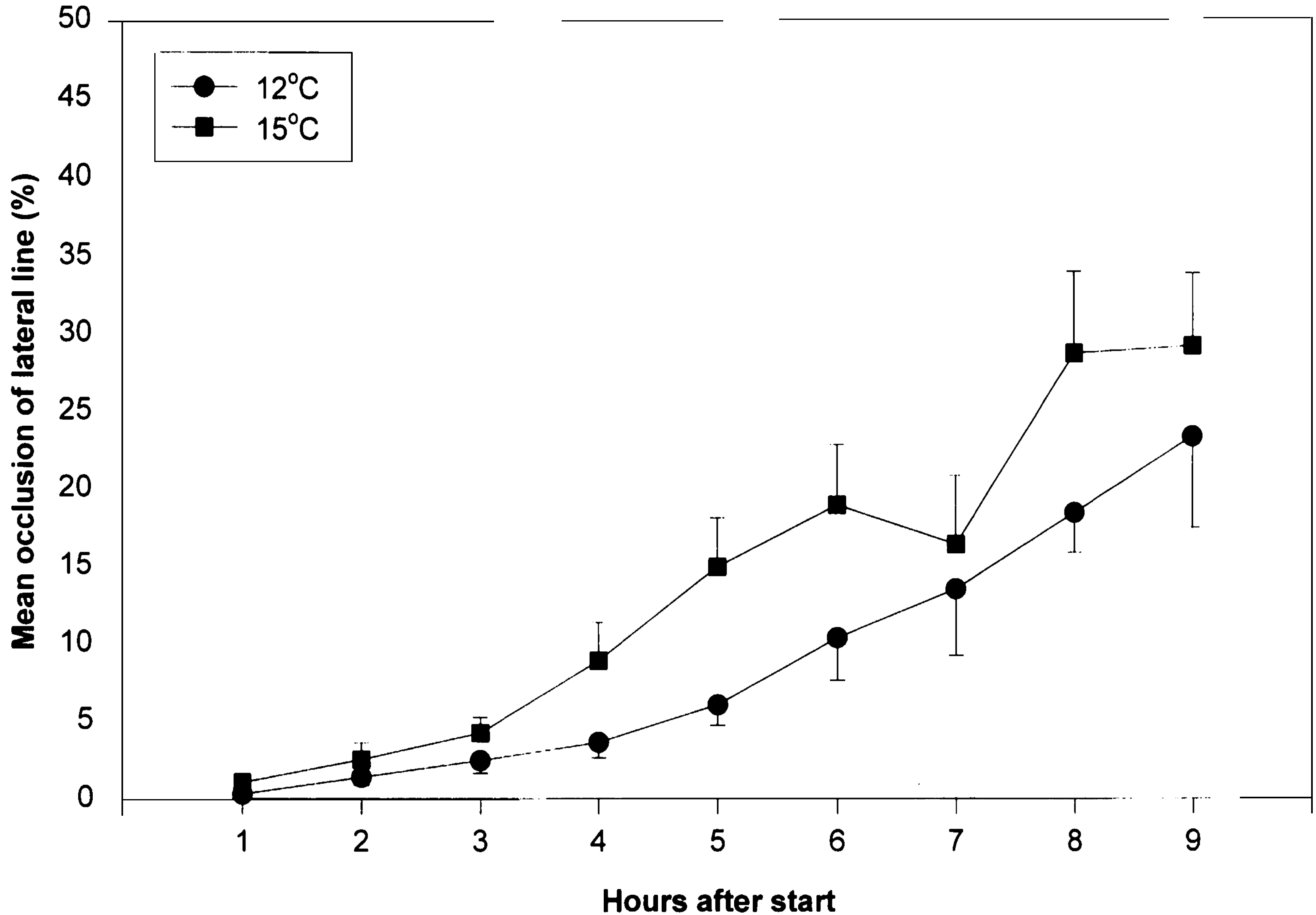

Figure 2.--Mean and SE) percent of he lateral line occluded with bubbles in juvenile spring chinook salmon during exposure to 130% TDG at 12^{o}C and 15^{o}C.

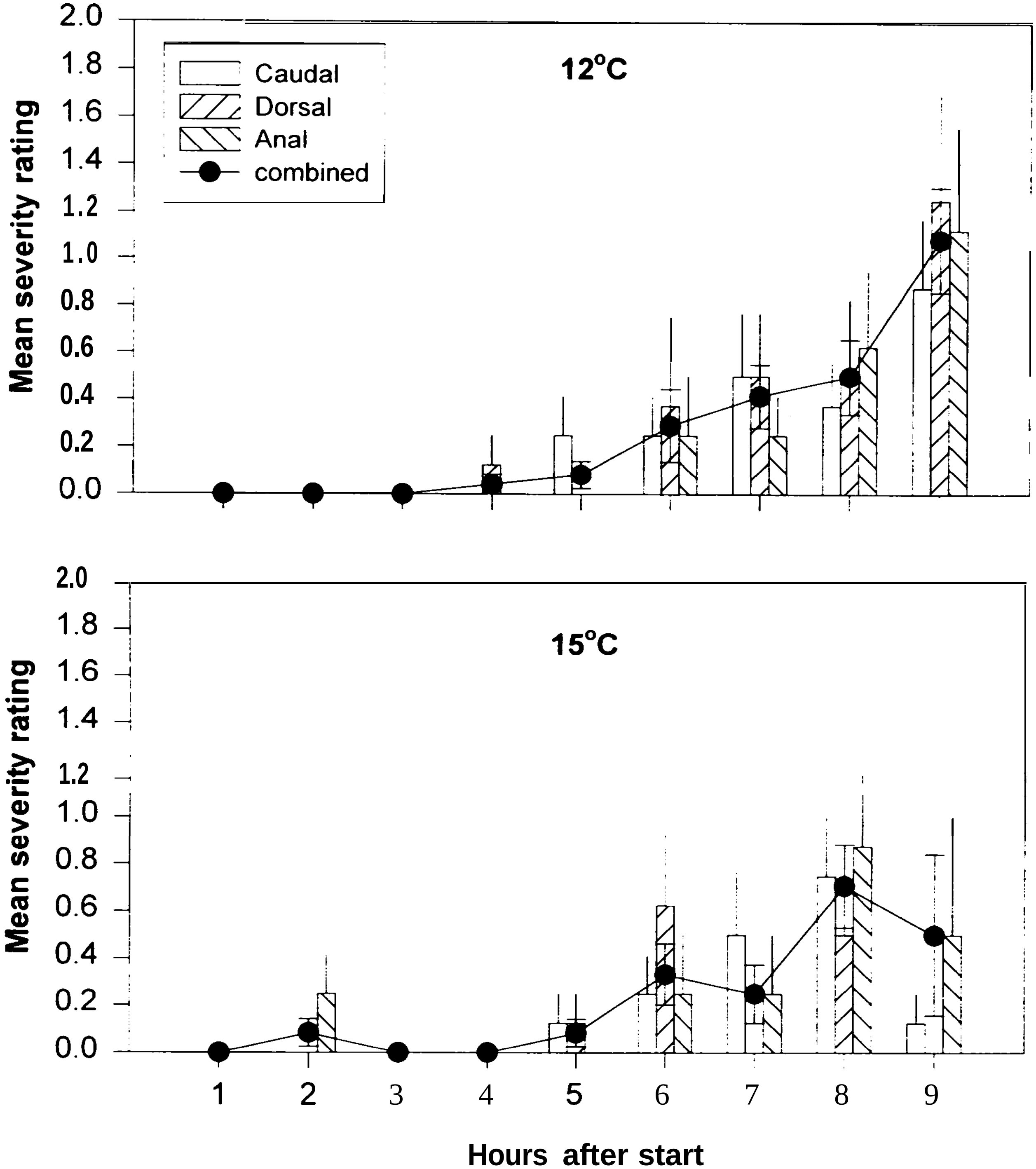

Figure 3.--Mean (and SE) severity ratings of bubbles in the fins of juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Bars represent averages derived from fins on 8 fish; points are the average of the bars at each time interval.

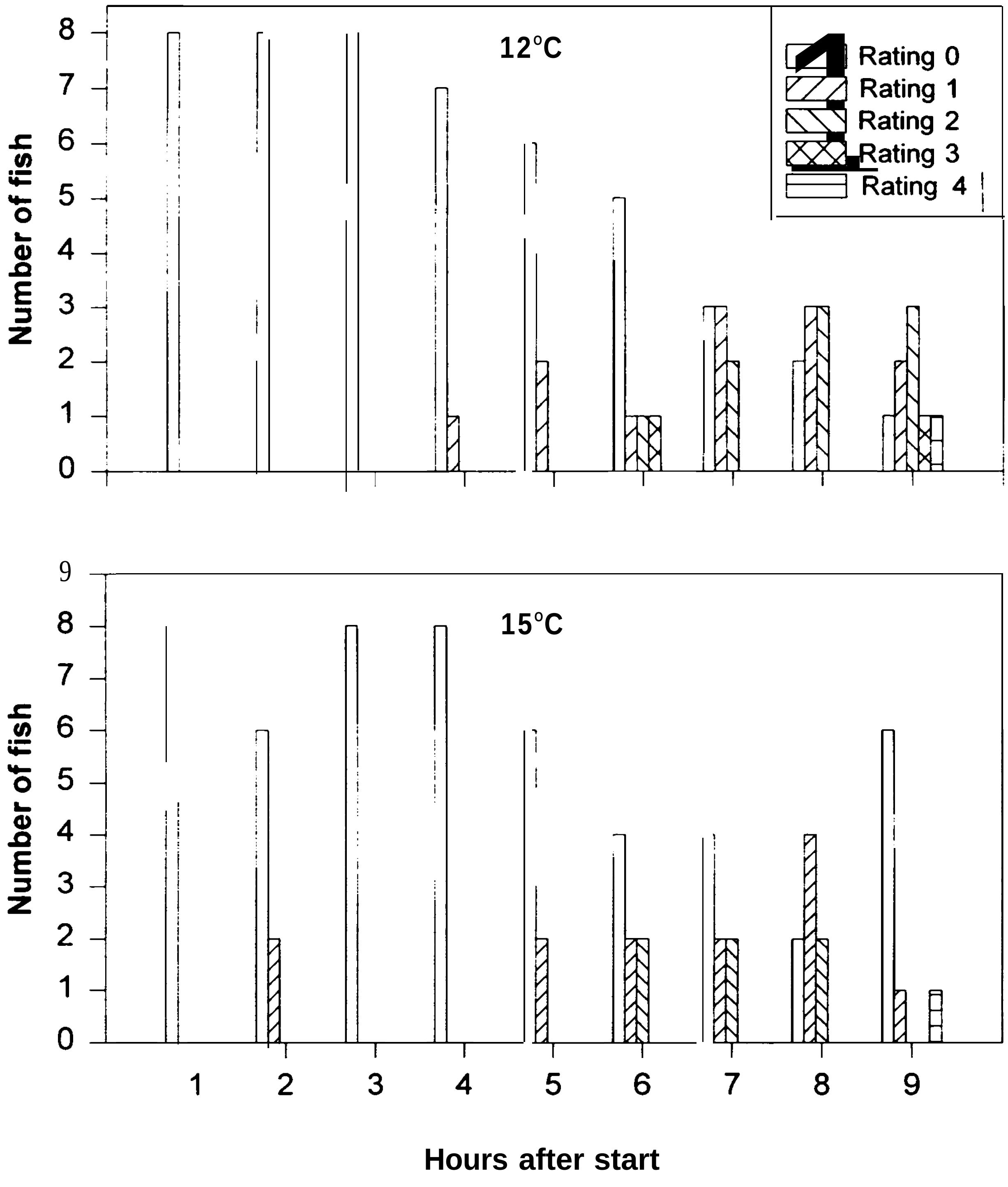

Figure 4.--Maximum severity ratings of bubbles in fins of juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Ratings derived from all fins combined.

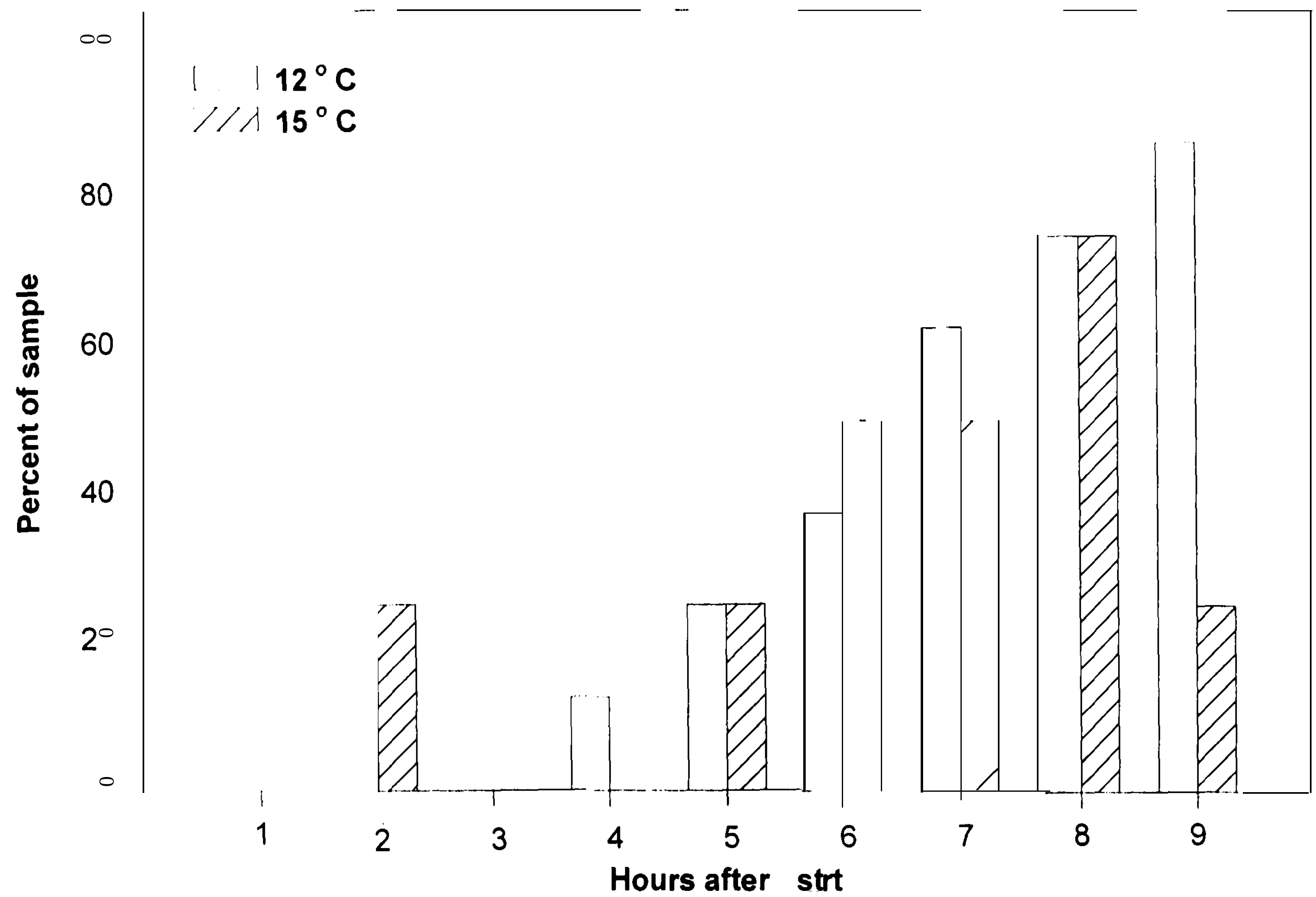

Figure 5.--Prevalence (N = 8/bar) of bubbles in fins of juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Data derived from all fins combined.

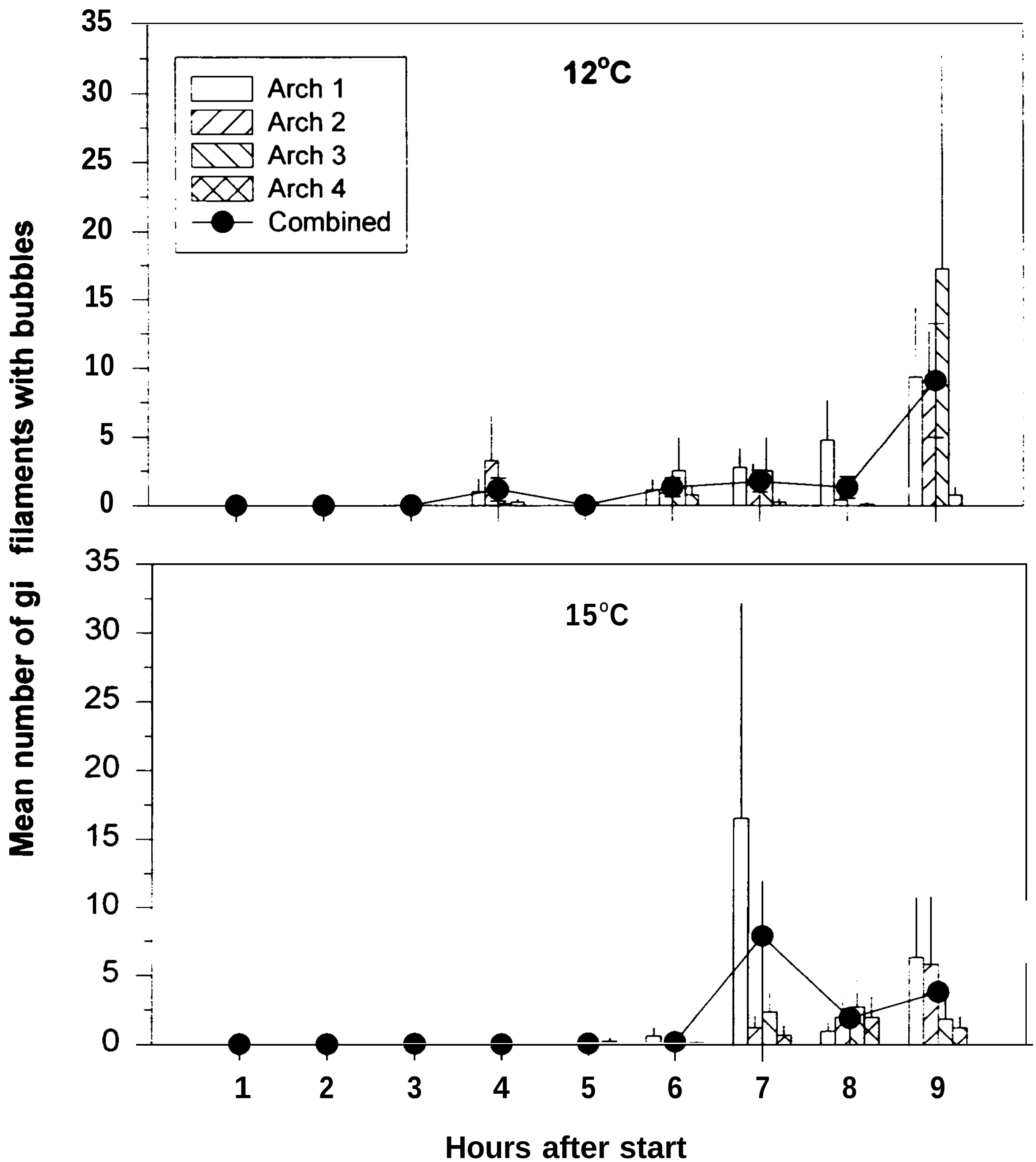

Figure 6.--Mean (and SE) count of gill filaments with bubbles in juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Bars represent averages from individual arches on 8 fish; points are the average of the bars at each time interval.

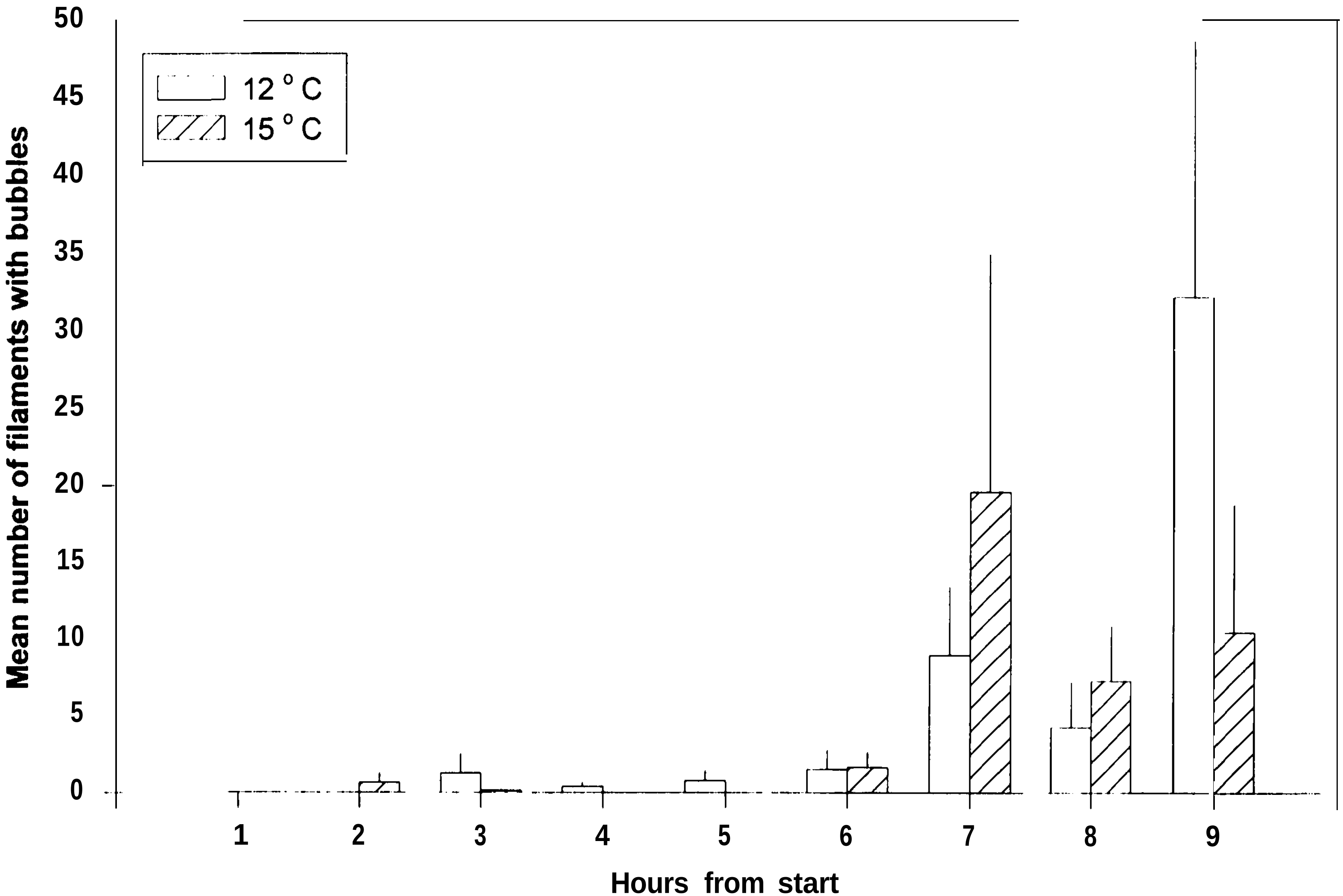

Figure 7.--Mean (and SE) number of gill filaments with bubbles in juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Data represents gill filaments cut off the first gill arch.

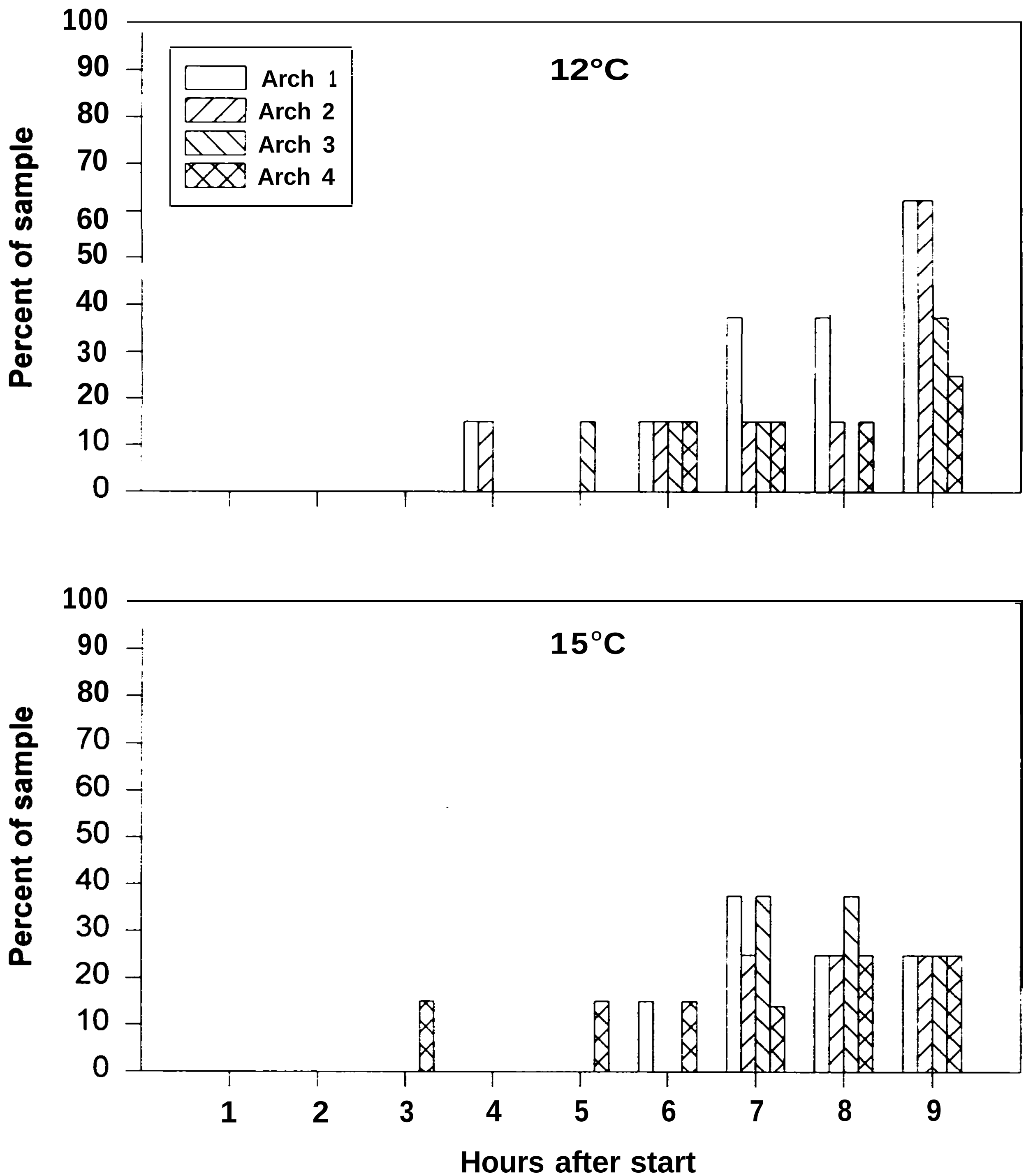

Figure 8.--Prevalence of bubbles in individual gill arches of juvenile spring chinook salmon during exposure to 130% at 12°C and 15°C.

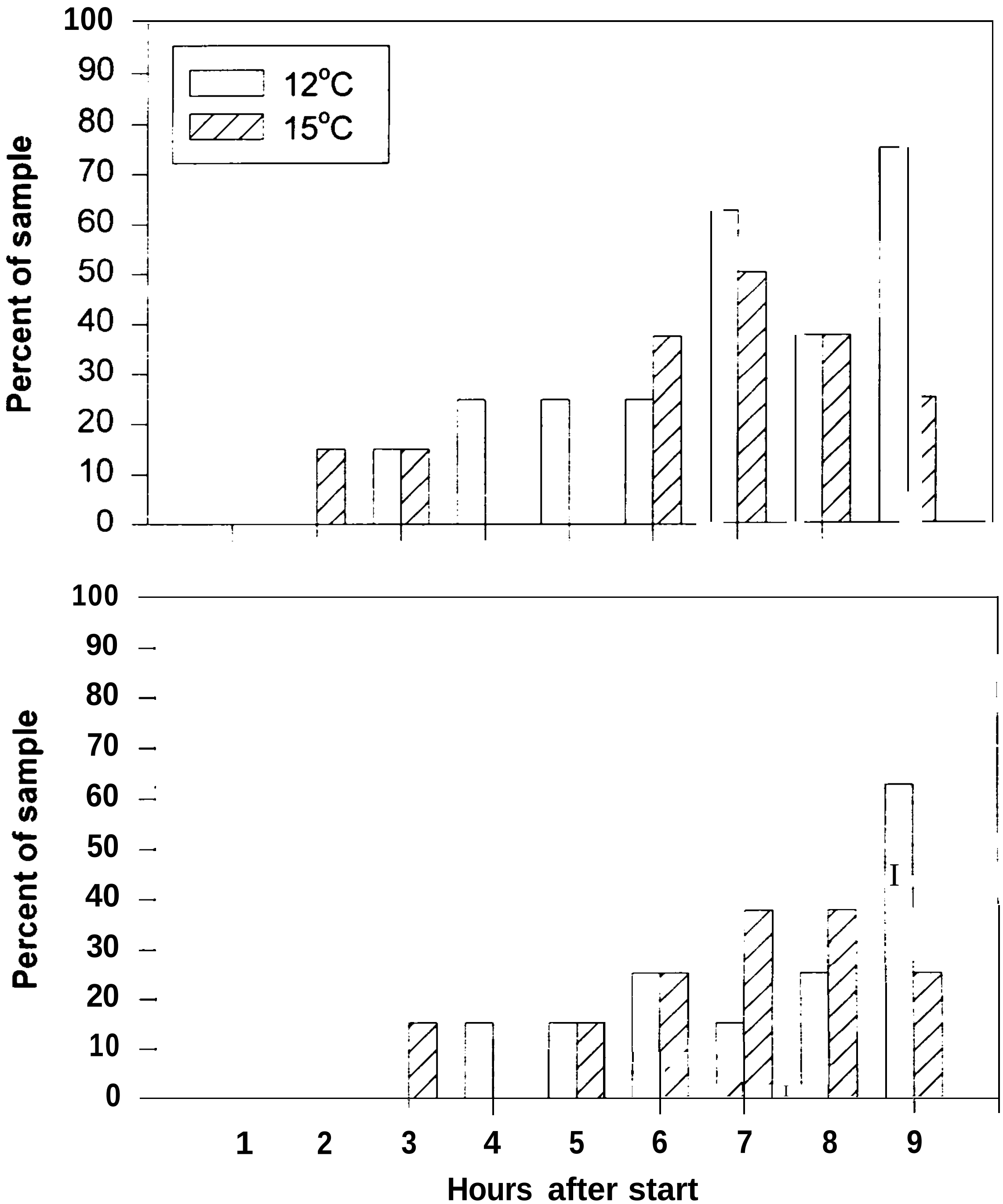

Figure 9.--Prevalance (N = 8/bar) of gill filaments with bubbles in juvenile spring chinook salmon during exposure to 130% TDG at 12°C and 15°C. Data represents gill filaments cut off the first gill arch (top) and all arches combined (bottom).

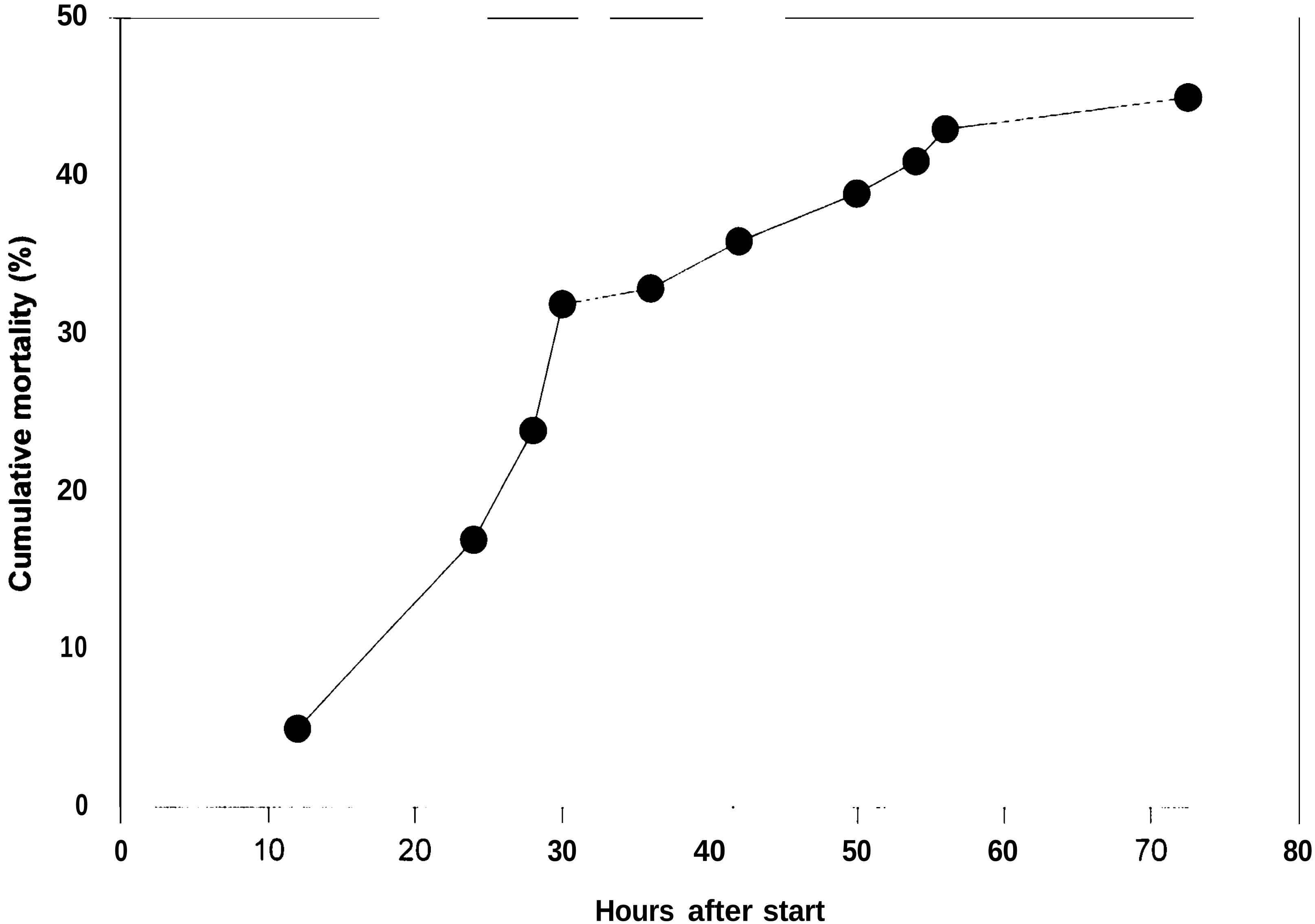

Figure 10.--Cumulative mortality of juvenile spring chinook salmon during exposures to 120% TDG at 12°C. Total number of fish exposed was 75.

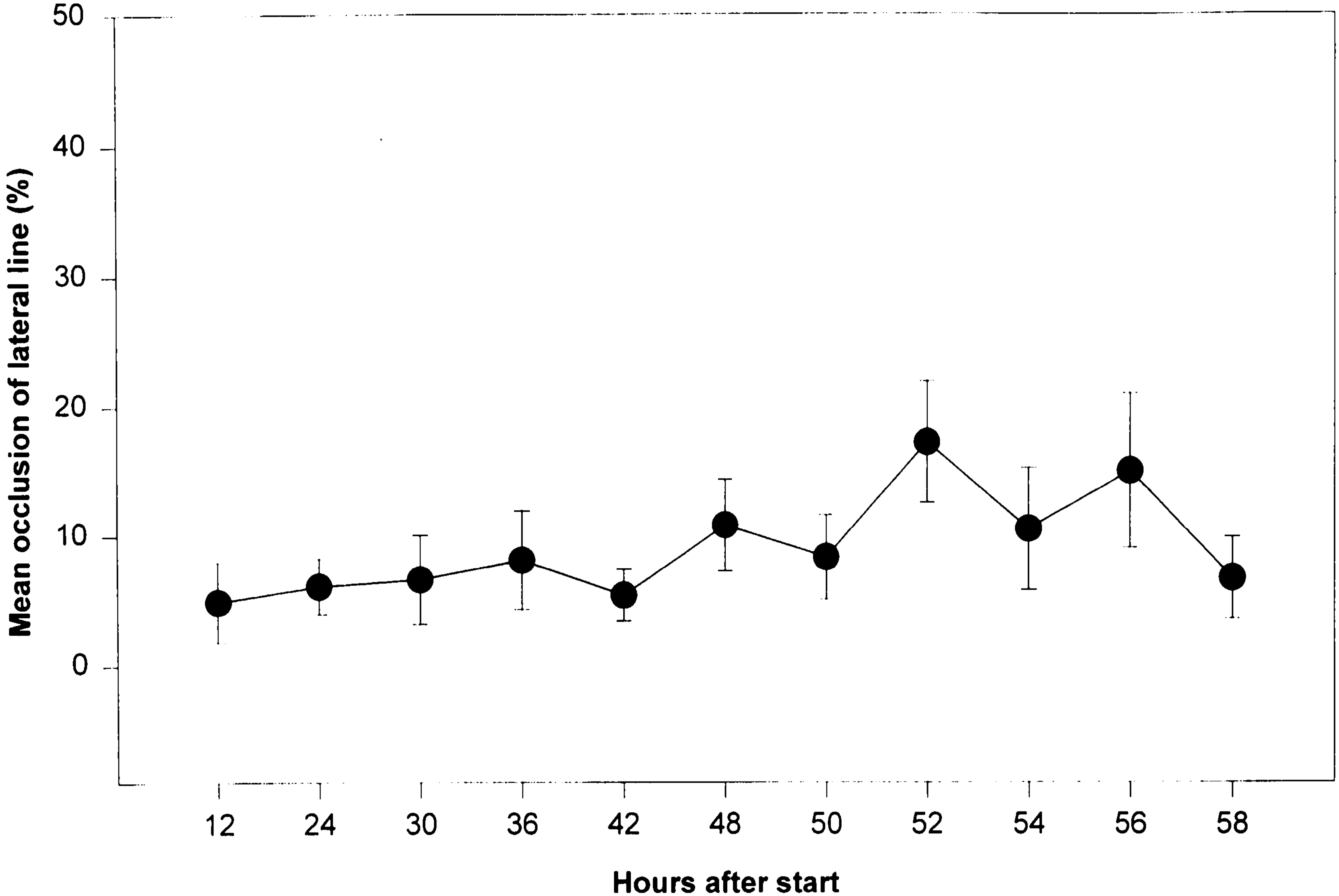

Figure 11.--Mean (± SE; N = 8/point) lateral line occlusion in juvenile spring chinook salmon during exposure to 120% TDG at 12°C.

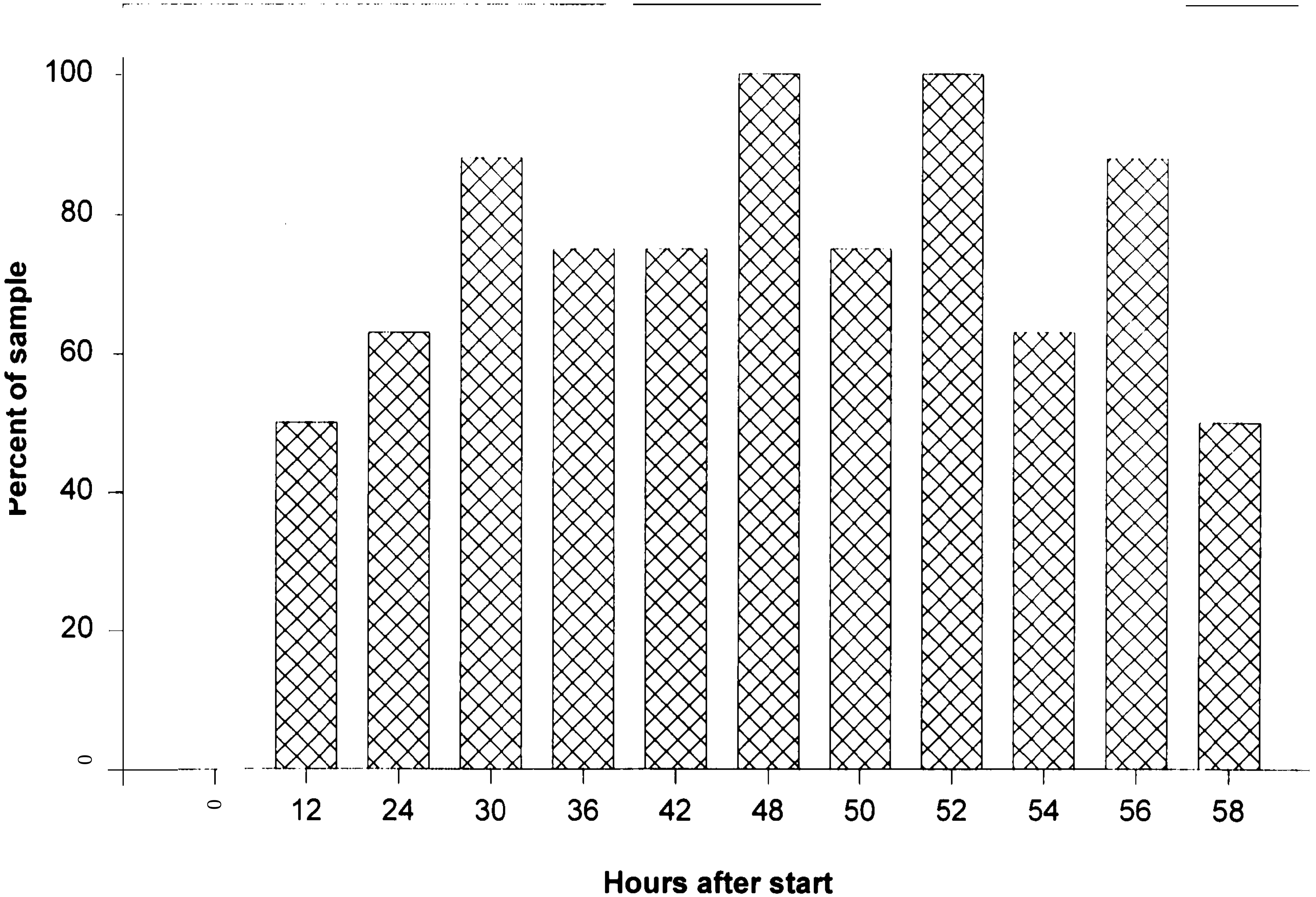

Figure 12.--Prevalence (N = 8/bar of lateral line bubbles in juvenile spring chinook salmon during exposure to 120% TDG at 12^{o}C.

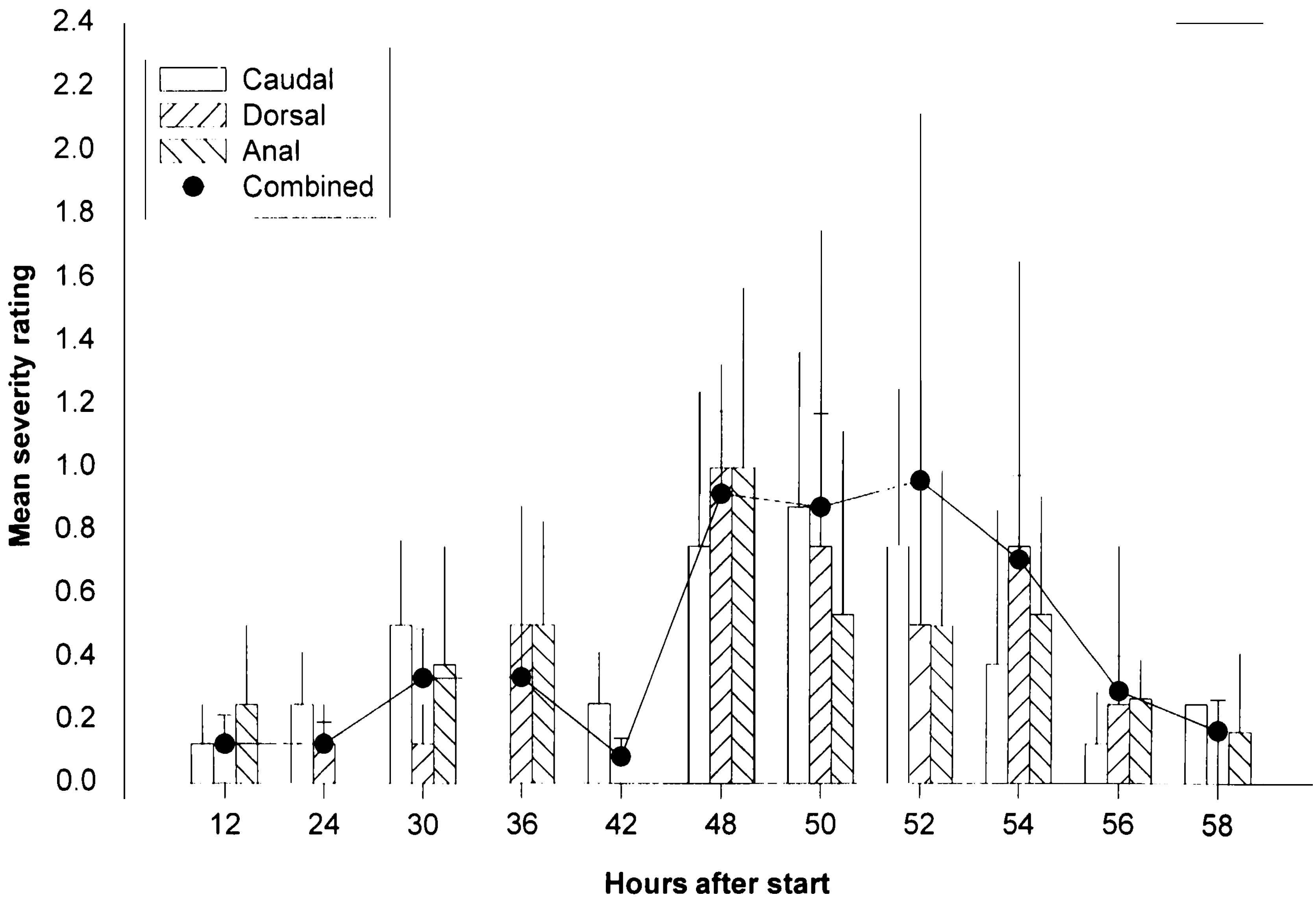

Figure 1 X--Mean (and SE) severity ratings of bubbles in fins of juvenile chinook salmon during exposure to 120% TDG at 12 C. Bars represent averages from fins on 8 fish; points are the average of the bars at each time interval.

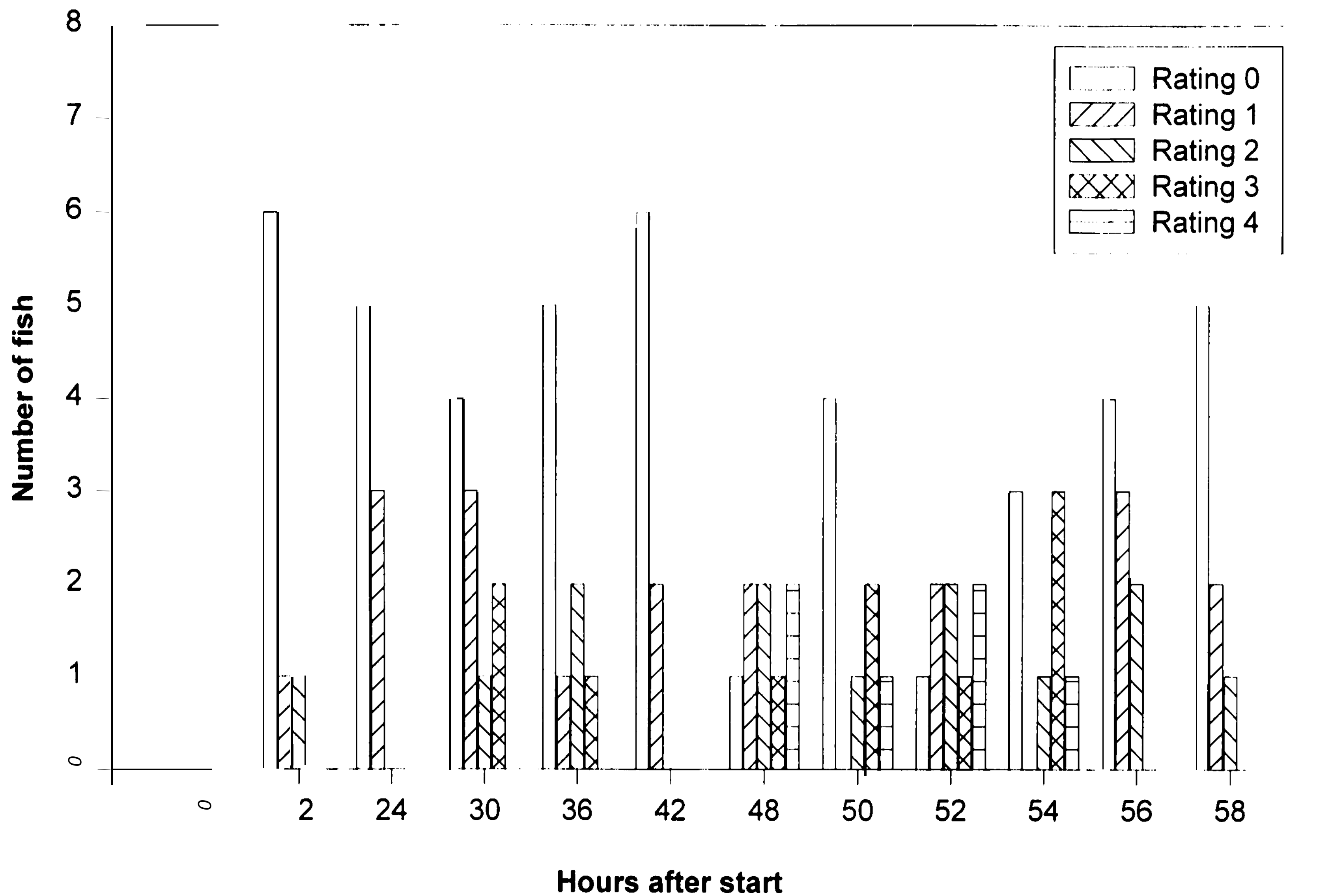

Figure 14.--Maximum severity ratings of bubbles in fins of juvenile chinook salmon during exposure to 120% TDG at 12^{o}C. Ratings derived from all fins combined.

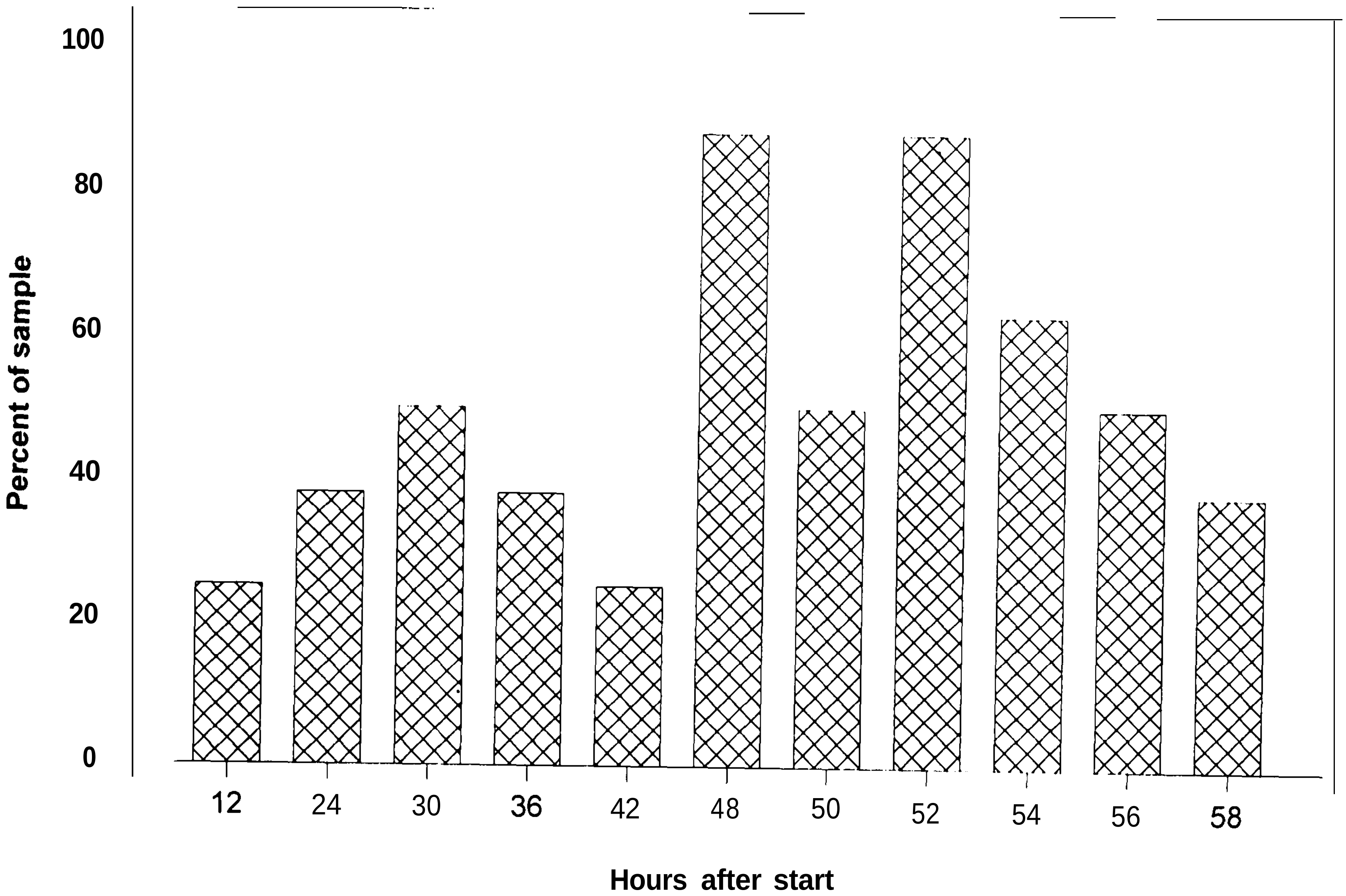

Figure 15.--Prevalence (N = 8/bar) of fin bubbles in juvenile chinook salmon during exposure to 120% TDG at 12°C.

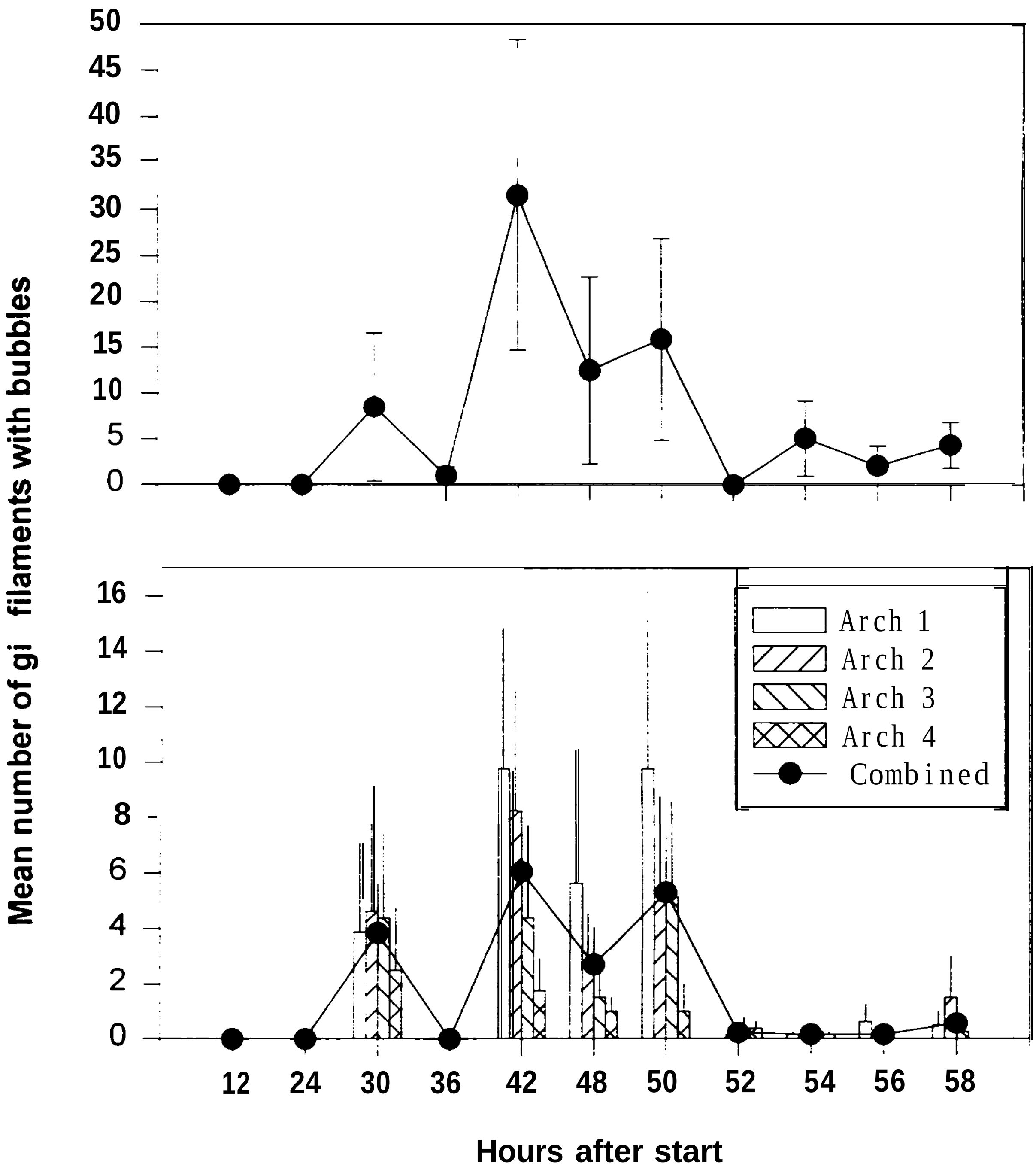

Figure 16.--Mean (and SE) count of gill filaments with bubbles from filaments cut off the first arch (top) and arches combined (bottom) on juvenile spring chinook salmon during exposure to 120% TDG at 12°C. Bars represent averages from individual arches on 8 fish; points are the average of the bars at each time interval.

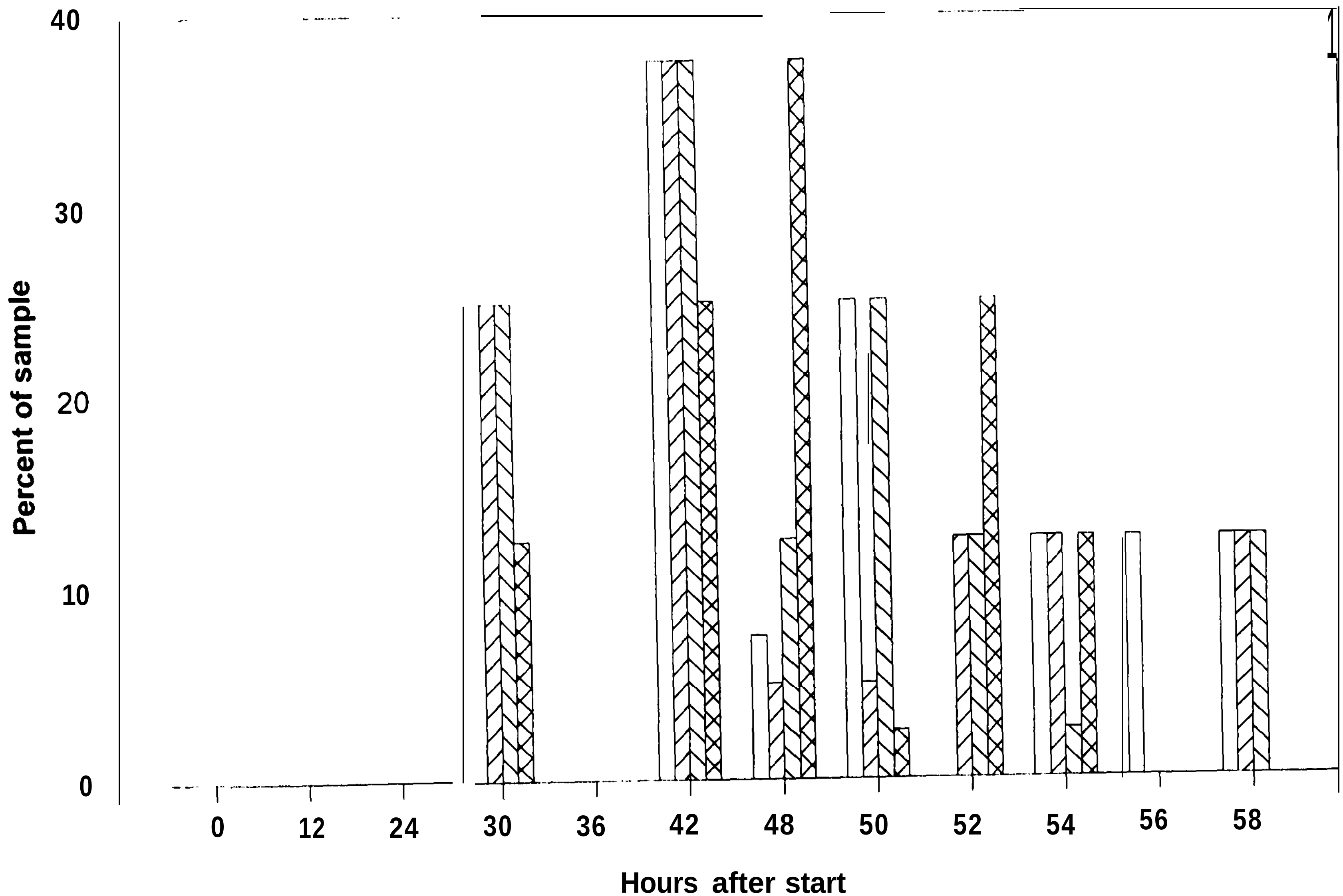

Figure 17.--Prevalence of bubbles in individual gill arches of juvenile spring chinook salmon during exposure to 120% TDG at 12°C.

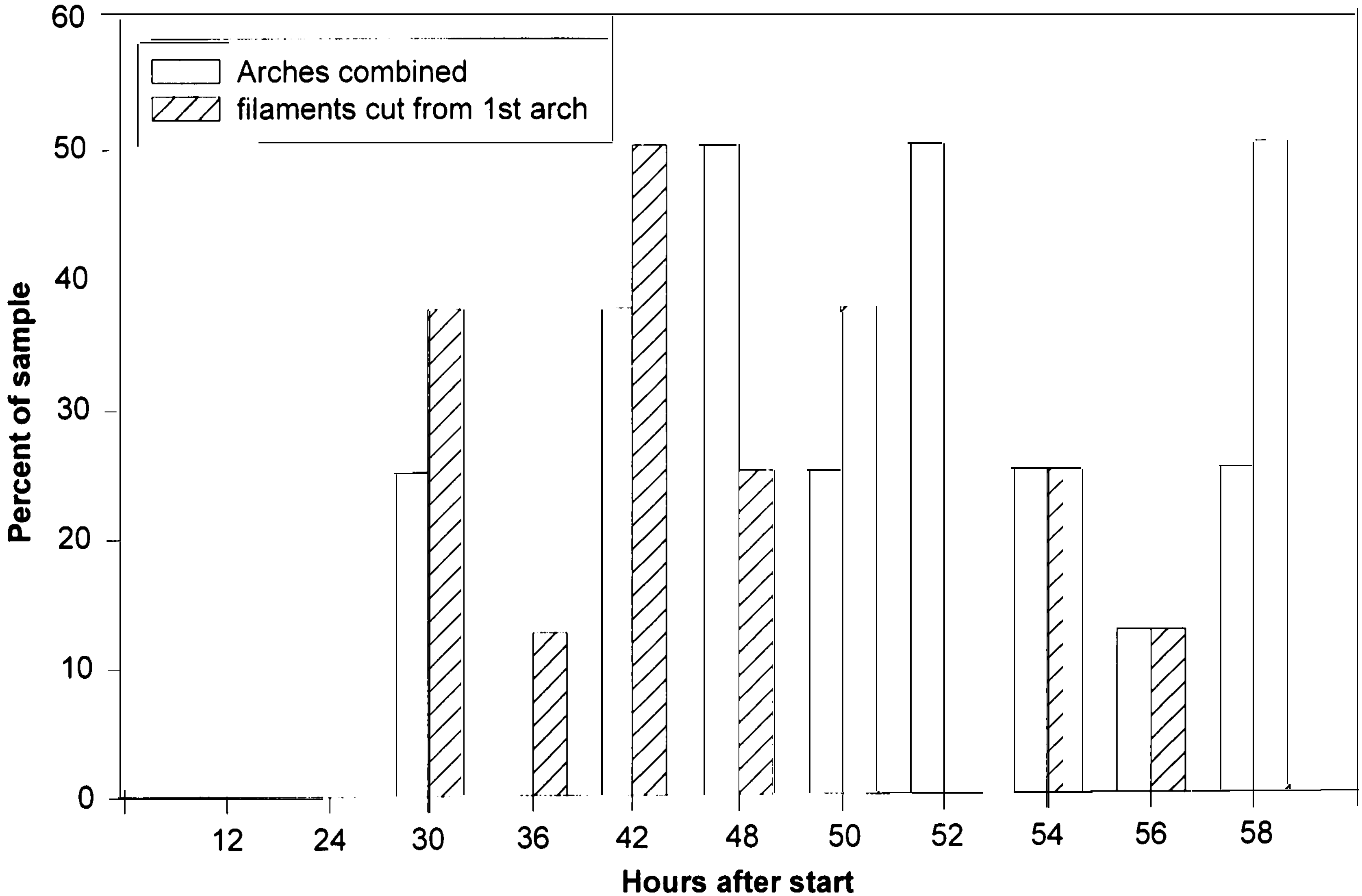

Figure 18.--Prevalence (N=8/bar) of gill bubbles in juvenile chinook during exposure to 120% TDG at 12°C. Data derived from four individual arches combined or from the filaments cut off the first gill arch.

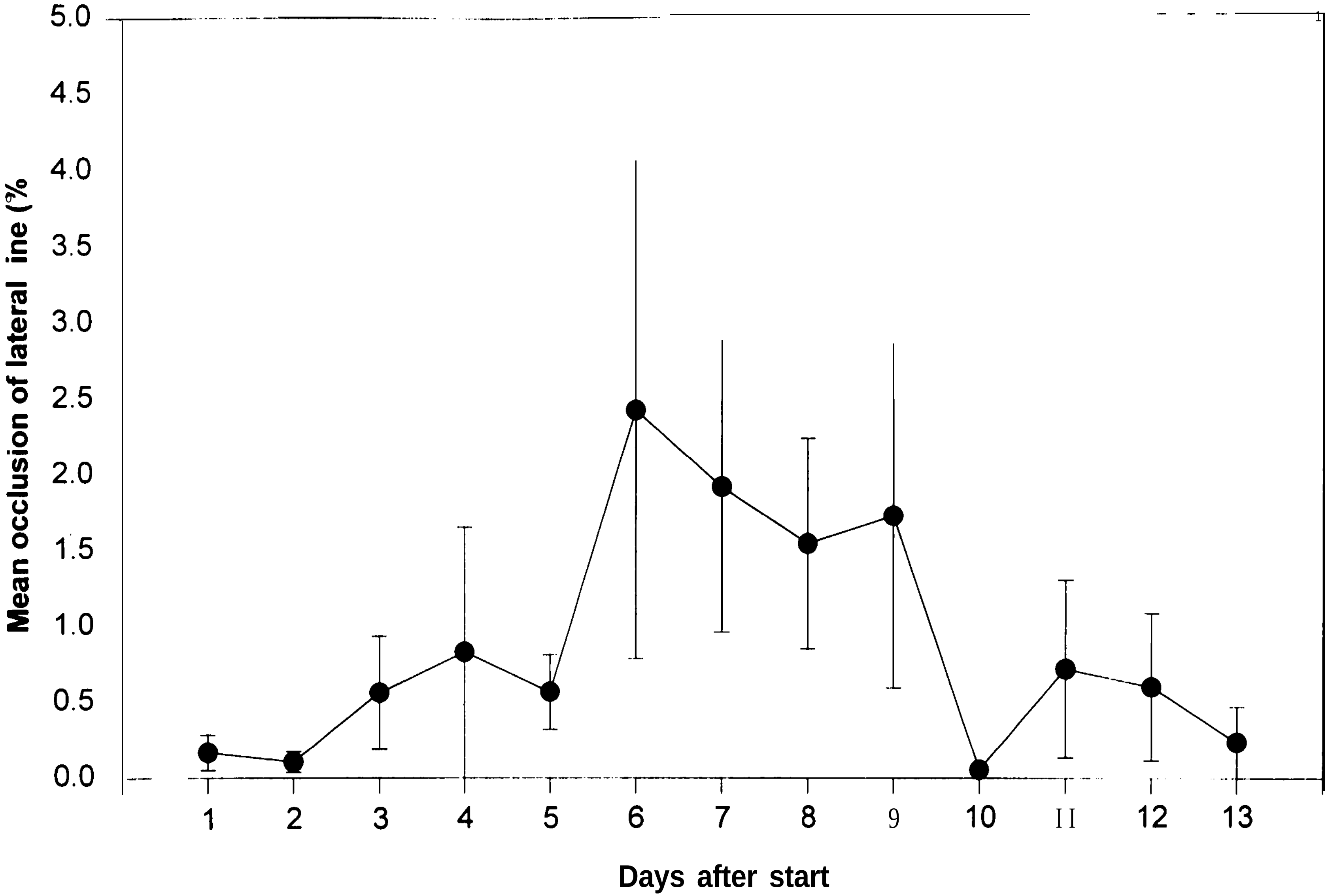

Figure 19.--Mean (and SE) of percent of lateral line (N = 8/bar) occluded with bubbles in juvenile spring chinook salmon during exposure to 110% TDG at 12°C.

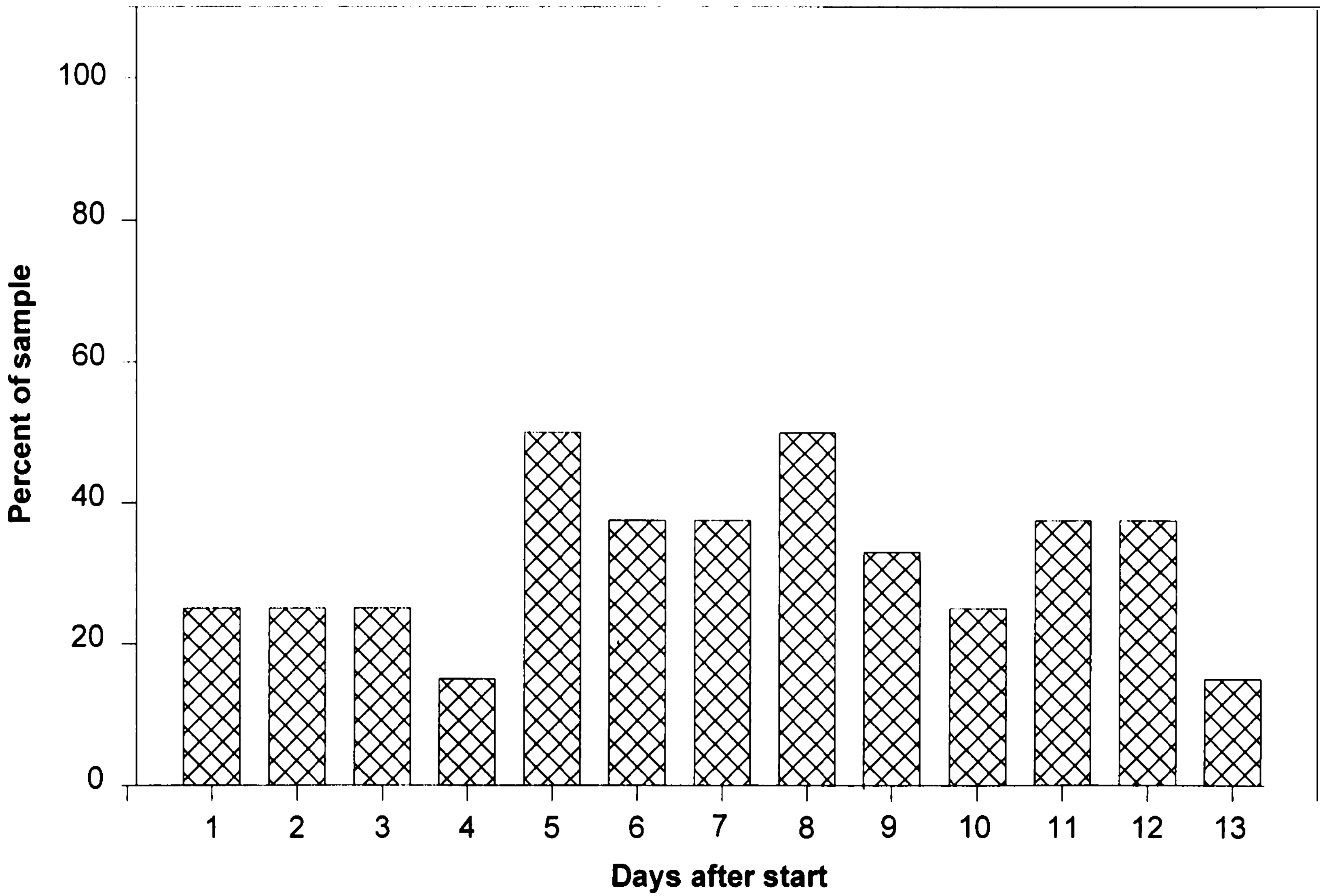

Figure 20.--Prevalence (N = 8/bar) of lateral line bubbles in juvenile spring chinook salmon during exposure to 11=% TDG at 12°C.

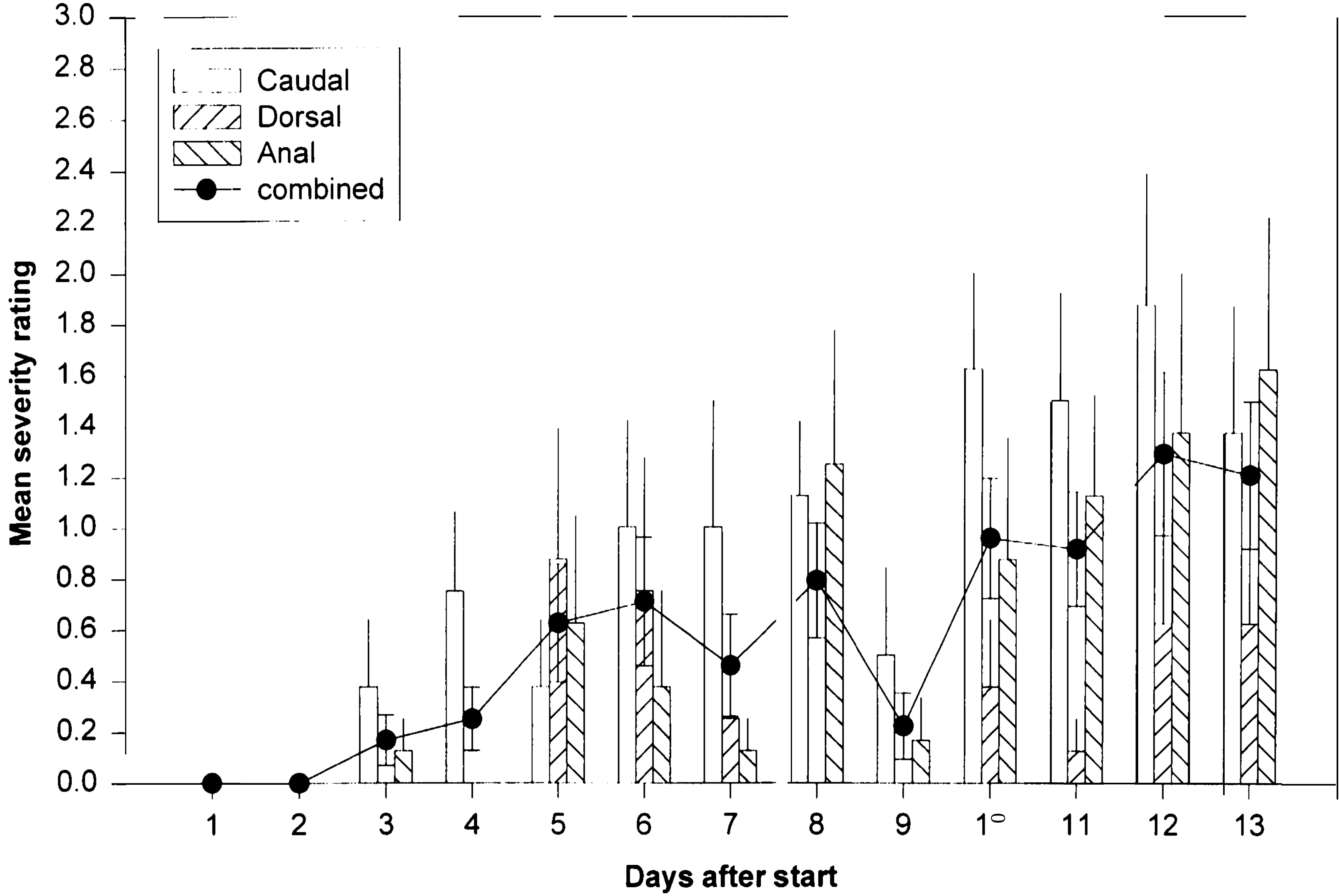

Figure 21.--Mean and SE) severity ratings of fins on juvenile spring chinook salmon during exposure to 110% TDG at 12°C. Bars represent averages derived from fins on 8 fish; points are the average of the bars at each time interval

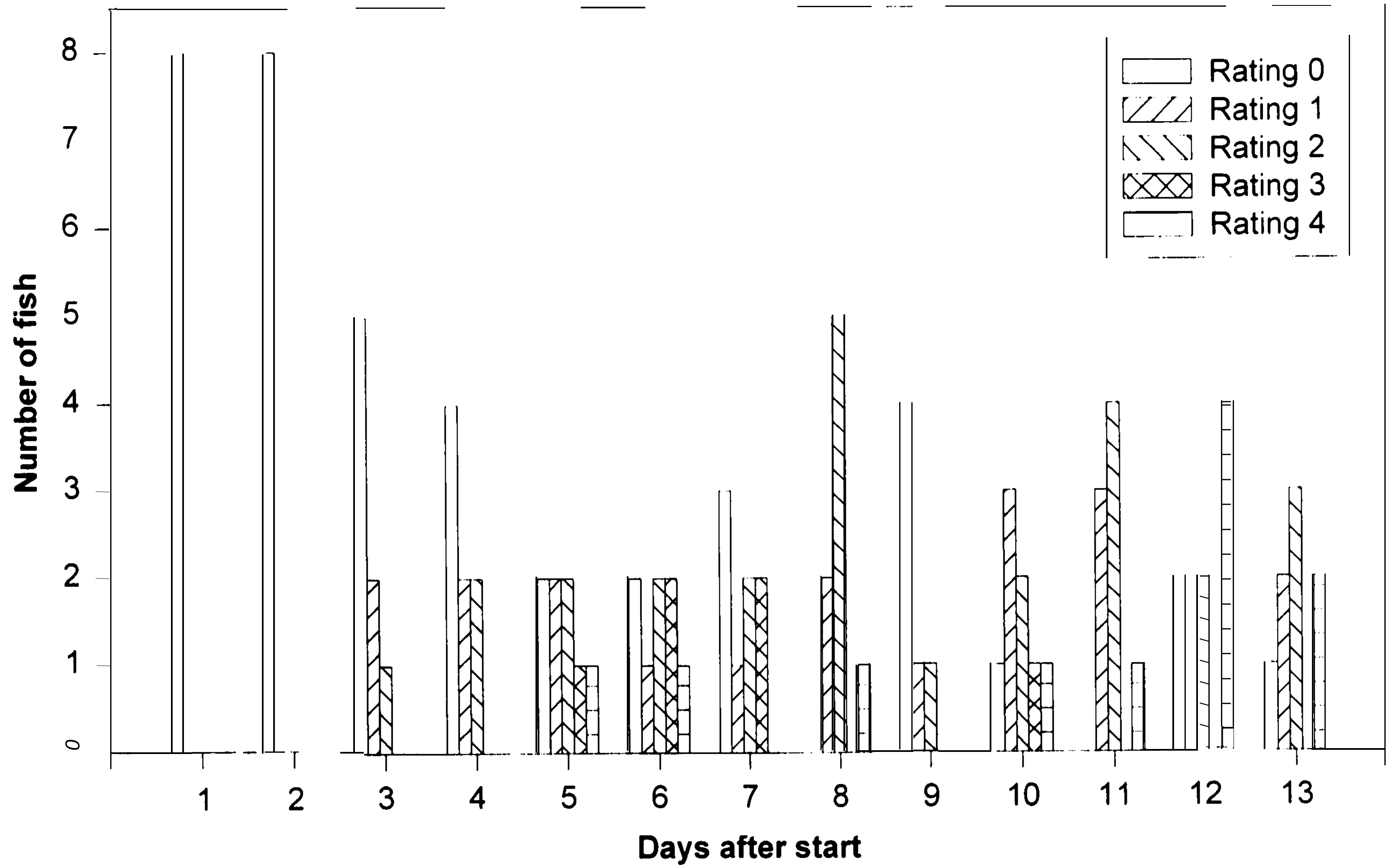

Figure 22.--Maximum severity ratings of bubbles in fins of juvenile spring chinook salmon during exposure to 110% at 12°C. Ratings derived from caudal dorsal and anal fins combined. Sample size was 6 for he 9th day only.

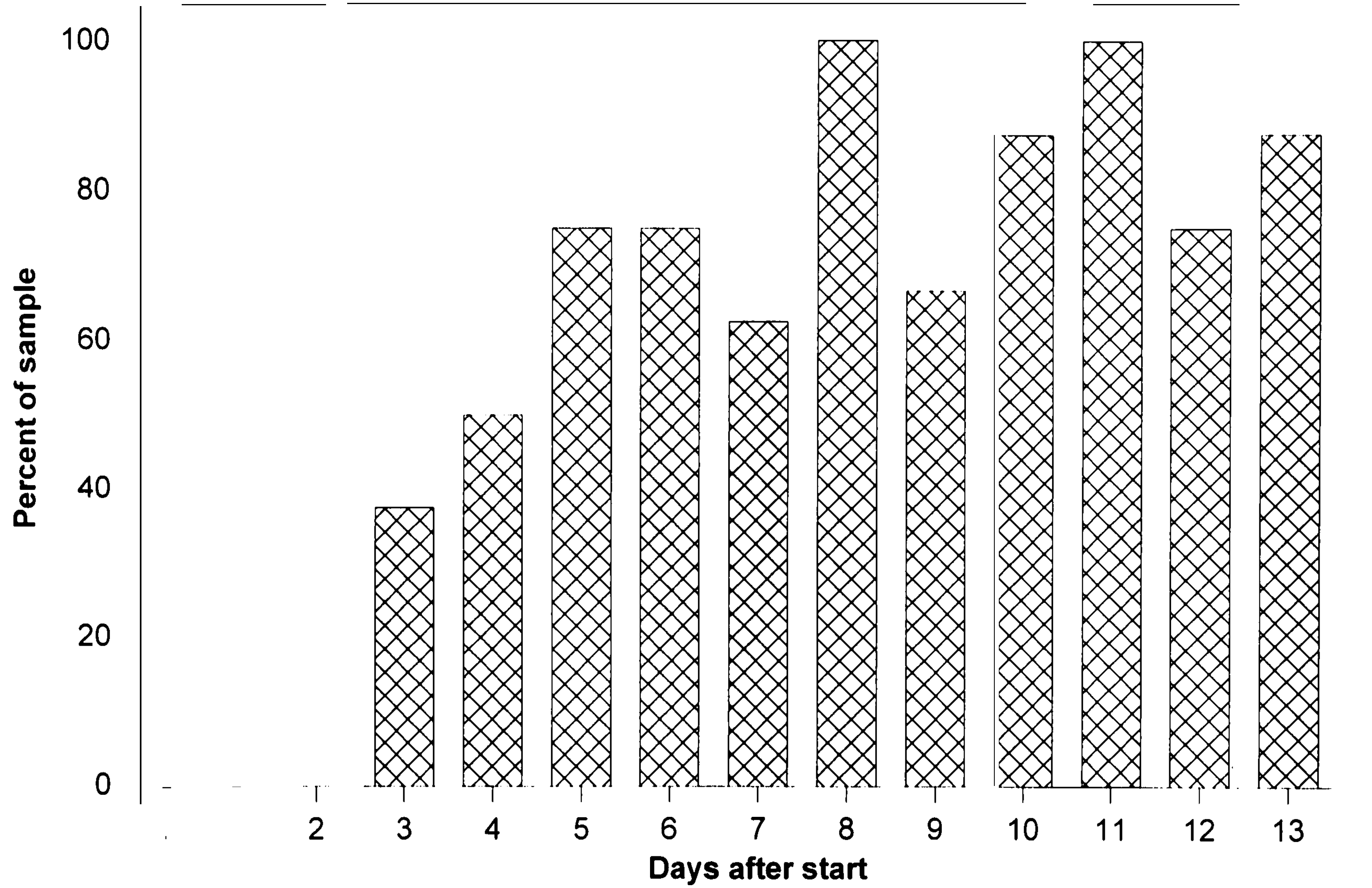

Figure 23.--Prevalence of bubbles in fins of juvenile spring chinook salmon during exposure ○ 11○% TDG at 12°C.

Appendices

Appendix 1. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at Lower Granite Dam (LGR) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
LGR	22APR	5	146.0	17.51	5	0.0000	0.000	5	0.000	0.000	5	0.000	0.000	5	0.000	0.000	5	0.000	0.000
	24APR	27	141.7	3.78	27	0.0000	0.000	27	0.000	0.000	27	0.000	0.000	27	0.000	0.000	27	0.000	0.000
	26APR	34	129.5	2.18	34	0.0000	0.000	34	0.000	0.000	34	0.000	0.000	34	0.000	0.000	34	0.000	0.000
	30APR	50	141.5	2.48	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	02MAY	50	138.1	1.90	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	04MAY	50	139.2	1.87	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	06MAY	50	136.3	2.09	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	08MAY	31	134.8	1.86	31	0.0000	0.000	31	0.000	0.000	31	0.000	0.000	31	0.000	0.000	31	0.000	0.000
	10MAY	50	134.7	1.70	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	12MAY	50	142.0	1.56	50	0.0260	0.026	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	14MAY	50	140.8	1.45	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	16MAY	49	136.2	1.55	49	0.0000	0.000	49	0.000	0.000	49	0.000	0.000	49	0.020	0.020	49	0.000	0.000
	18MAY	50	134.4	1.60	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	20MAY	50	135.5	1.59	50	0.0120	0.012	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000
	22MAY	9	132.6	2.35	9	0.0000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000
	24MAY	3	134.3	3.18	3	0.0000	0.000	3	0.000	0.000	3	0.000	0.000	3	0.000	0.000	3	0.000	0.000
	26MAY	4	140.8	2.29	4	0.0000	0.000	4	0.000	0.000	4	0.000	0.000	4	0.000	0.000	4	0.000	0.000
	28MAY	7	142.4	3.00	7	0.0000	0.000	7	0.000	0.000	7	0.000	0.000	7	0.000	0.000	7	0.000	0.000
	30MAY	2	146.0	11.00	2	0.0000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000

Appendix 2. Sample size (N), mean and standard error (stderr) for steelhead sampled for signs of gas bubbles trauma at Lower Granite Dam (LGR) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
LGR	15APR	50	211.1	2.66	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	17APR	50	218.9	3.11	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	19APR	17	221.1	3.96	17	0.0000	0.000	17	0.000	0.000	17	0.000	0.000	17	0.000	0.000	17	0.000	0.000
	22APR	96	203.2	2.27	96	0.0000	0.000	96	0.000	0.000	96	0.000	0.000	96	0.000	0.000	96	0.000	0.000
	24APR	50	199.3	4.30	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	26APR	50	199.6	3.55	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	30APR	50	210.0	3.10	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	02MAY	50	200.7	3.00	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	04MAY	50	194.5	4.22	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	06MAY	50	194.0	3.60	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.080	0.039	50	0.000	0.000
	08MAY	36	190.9	3.59	36	0.0000	0.000	36	0.000	0.000	36	0.000	0.000	36	0.028	0.028	36	0.000	0.000
	10MAY	50	198.0	2.88	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	12MAY	50	178.7	3.73	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	14MAY	50	188.8	3.69	50	0.0060	0.006	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	16MAY	50	170.9	3.31	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	18MAY	50	172.3	3.24	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	20MAY	50	195.3	3.73	50	0.0120	0.008	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	22MAY	50	186.2	3.18	50	0.0180	0.011	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	24MAY	50	178.3	2.83	50	0.0100	0.007	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	26MAY	50	187.5	2.97	50	0.0020	0.002	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	28MAY	50	198.4	3.62	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	30MAY	50	203.0	3.16	50	0.0740	0.060	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01JUN	50	202.6	3.43	50	0.0660	0.058	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	03JUN	50	207.8	3.46	50	0.0040	0.003	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	05JUN	50	205.2	3.20	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	07JUN	50	204.5	3.06	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	09JUN	50	197.5	2.66	50	0.0240	0.024	50	0.020	0.020	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	11JUN	50	202.5	3.51	50	0.0220	0.015	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	13JUN	50	199.5	3.65	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.040	0.028	50	0.040	0.040
	15JUN	50	208.3	3.90	50	0.0040	0.004	50	0.060	0.034	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	17JUN	50	210.4	3.14	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	19JUN	50	205.6	3.75	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	23JUN	8	218.5	8.22	8	0.1500	0.136	8	0.125	0.125	8	0.000	0.000	8	0.000	0.000	8	0.000	0.000
	25JUN	11	211.1	10.86	11	0.0000	0.000	11	0.182	0.122	11	0.000	0.000	11	0.000	0.000	11	0.364	0.364
	27JUN	3	201.3	17.61	3	0.0000	0.000	3	0.000	0.000	3	0.000	0.000	3	0.000	0.000	3	0.000	0.000

Appendix 3. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at Little Goose Dam (LGS) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
LGS	19APR	6	159.2	6.11	6	0.0000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000
	21APR	23	132.6	5.33	23	0.0000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000
	23APR	9	122.0	5.38	9	0.0000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000
	26APR	50	130.7	3.39	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	28APR	50	143.7	3.55	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29APR	50	137.5	3.05	50	0.0540	0.054	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01MAY	50	137.8	1.63	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	03MAY	50	136.5	2.78	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	05MAY	50	135.2	1.26	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	07MAY	50	140.2	2.29	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	09MAY	50	134.5	1.53	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	11MAY	50	134.4	1.39	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	13MAY	50	139.2	1.35	50	0.0000	0.000	50	0.100	0.043	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	15MAY	50	140.1	1.90	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	17MAY	50	141.2	2.06	50	0.0000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.040	0.028	50	0.000	0.000
	19MAY	50	144.5	1.57	50	0.4520	0.452	50	0.020	0.020	50	0.020	0.020	50	0.020	0.020	50	0.000	0.000
	21MAY	24	136.3	2.33	24	2.0292	2.029	24	0.125	0.092	24	0.000	0.000	24	0.042	0.042	24	0.000	0.000
	23MAY	50	133.3	1.55	50	2.2660	1.345	50	0.120	0.068	50	0.080	0.063	50	0.000	0.000	50	0.000	0.000
	25MAY	50	136.7	1.86	50	0.2300	0.161	50	0.040	0.040	50	0.060	0.044	50	0.000	0.000	50	0.000	0.000
	27MAY	50	137.3	1.65	50	0.2580	0.181	50	0.040	0.040	50	0.040	0.040	50	0.000	0.000	50	0.000	0.000
	29MAY	35	145.1	2.69	35	0.0000	0.000	35	0.029	0.029	35	0.057	0.057	35	0.057	0.057	35	0.000	0.000
	31MAY	12	143.2	5.99	12	0.0000	0.000	12	0.000	0.000	12	0.000	0.000	12	0.000	0.000	12	0.000	0.000
	02JUN	5	137.4	4.09	5	0.0000	0.000	5	0.000	0.000	5	0.000	0.000	5	0.000	0.000	5	0.000	0.000
	04JUN	2	156.0	14.00	2	0.0000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000

Appendix 4. Sample size (N), mean and standard error (stderr) for steelhead sampled for signs of gas bubbles trauma at Little Goose Dam (LGS) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
LGS	16APR	50	205.1	4.77	50	0.0280	0.028	50	0.520	0.115	50	0.420	0.115	50	0.160	0.083	50	0.000	0.000
	19APR	37	214.9	4.17	37	0.0000	0.000	37	0.027	0.027	37	0.000	0.000	37	0.000	0.000	37	0.000	0.000
	21APR	50	225.7	3.02	50	0.0000	0.000	50	0.020	0.020	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000
	23APR	50	218.1	3.48	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	26APR	50	206.9	3.66	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	28APR	50	190.2	4.64	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29APR	50	213.8	3.36	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01MAY	50	209.8	3.67	50	0.0260	0.026	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	03MAY	50	213.2	3.88	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	05MAY	50	199.1	3.02	50	0.0000	0.000	50	0.060	0.044	50	0.000	0.000	50	0.120	0.062	50	0.000	0.000
	07MAY	50	210.3	3.88	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	09MAY	50	197.8	3.32	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	11MAY	50	210.7	3.53	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	13MAY	50	218.8	3.69	50	0.0020	0.002	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	15MAY	50	208.1	3.32	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	17MAY	50	192.9	3.99	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	19MAY	51	186.8	3.45	51	0.0000	0.000	51	0.039	0.027	51	0.020	0.020	51	0.020	0.020	51	0.000	0.000
	21MAY	50	203.7	4.13	50	1.4620	1.264	50	0.140	0.064	50	0.180	0.102	50	0.000	0.000	50	0.000	0.000
	23MAY	50	196.2	3.83	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	25MAY	50	204.9	3.83	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	27MAY	50	210.8	3.28	50	0.0180	0.018	50	0.040	0.040	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29MAY	50	217.9	5.06	50	0.0220	0.018	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	31MAY	50	212.9	4.18	50	0.0040	0.004	50	0.040	0.040	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	02JUN	50	204.5	4.68	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	04JUN	50	209.5	4.00	50	0.0540	0.054	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	06JUN	50	210.0	4.74	50	0.0200	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	08JUN	50	212.0	4.12	50	0.0460	0.046	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	10JUN	26	216.8	6.28	26	0.0000	0.000	26	0.077	0.053	26	0.038	0.038	26	0.115	0.064	26	0.000	0.000
	12JUN	48	221.1	4.26	48	0.0333	0.033	48	0.000	0.000	48	0.021	0.021	48	0.000	0.000	48	0.000	0.000
	14JUN	50	208.7	3.81	50	0.0000	0.000	50	0.000	0.000	50	0.140	0.086	50	0.040	0.040	50	0.000	0.000
	16JUN	50	218.6	4.23	50	0.0120	0.012	50	0.040	0.040	50	0.080	0.048	50	0.000	0.000	50	0.000	0.000
	18JUN	50	213.1	4.47	50	0.0240	0.024	50	0.020	0.020	50	0.040	0.040	50	0.000	0.000	50	0.000	0.000
	20JUN	33	230.5	5.03	33	0.0000	0.000	33	0.000	0.000	33	0.061	0.061	33	0.000	0.000	33	0.000	0.000
	22JUN	50	215.7	4.68	50	0.0140	0.014	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	24JUN	50	228.4	5.31	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	26JUN	11	214.0	7.15	11	0.0818	0.082	11	0.000	0.000	11	0.000	0.000	11	0.000	0.000	11	0.000	0.000
	28JUN	8	215.9	8.47	8	0.0000	0.000	8	0.000	0.000	8	0.000	0.000	8	0.000	0.000	8	0.000	0.000
	30JUN	38	221.9	4.62	38	0.0000	0.000	38	0.000	0.000	38	0.000	0.000	38	0.000	0.000	38	0.000	0.000

Appendix 5. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at Lower Monumental Dam (LMN) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
LMN	15APR	14	153.2	4.99	14	0.0000	0.000	14	0.000	0.000	14	0.000	0.000	14	0.000	0.000	14	0.000	0.000
	18APR	10	165.5	5.02	10	0.0000	0.000	10	0.100	0.100	10	0.000	0.000	10	0.100	0.100	10	0.000	0.000
	20APR	55	150.3	3.16	55	0.0527	0.053	55	0.055	0.031	55	0.000	0.000	55	0.018	0.018	55	0.000	0.000
	22APR	50	143.9	3.53	50	0.0000	0.000	50	0.080	0.039	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	25APR	50	139.8	3.50	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	27APR	50	137.1	4.06	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	30APR	50	149.1	3.90	50	0.0000	0.000	50	0.040	0.028	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000
	02MAY	50	138.8	2.32	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	04MAY	50	143.1	2.38	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	06MAY	50	136.8	1.81	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	08MAY	50	136.7	2.34	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	10MAY	50	138.4	3.10	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.080	0.039	50	0.000	0.000
	12MAY	50	140.0	2.49	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	14MAY	50	143.6	2.02	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	16MAY	50	141.6	1.39	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	18MAY	50	146.6	1.65	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.060	0.034	50	0.000	0.000
	20MAY	50	145.6	1.45	50	0.0000	0.000	50	0.060	0.044	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	22MAY	51	145.1	1.54	51	0.0000	0.000	51	0.059	0.033	51	0.078	0.038	51	0.176	0.078	51	0.000	0.000
	24MAY	50	145.1	1.91	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	26MAY	50	142.0	2.53	50	0.0000	0.000	50	0.020	0.020	50	0.020	0.020	50	0.040	0.040	50	0.000	0.000
	28MAY	50	145.8	1.87	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	30MAY	50	144.2	1.87	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01JUN	14	145.7	2.77	14	0.0000	0.000	14	0.143	0.097	14	0.000	0.000	14	0.000	0.000	14	0.000	0.000
	03JUN	26	143.4	7.13	26	0.0154	0.015	26	0.231	0.084	26	0.000	0.000	26	0.000	0.000	26	0.000	0.000
	05JUN	13	135.6	4.30	13	0.0000	0.000	13	0.077	0.077	13	0.000	0.000	13	0.077	0.077	13	0.000	0.000
	07JUN	8	143.8	3.87	8	0.0000	0.000	8	0.000	0.000	8	0.000	0.000	8	0.000	0.000	8	0.000	0.000
	09JUN	4	147.5	5.95	4	0.0000	0.000	4	0.000	0.000	4	0.000	0.000	4	0.000	0.000	4	0.000	0.000

Appendix 6. Sample size (N), mean and standard error (stderr) for steelhead sampled for signs of gas bubbles trauma at Lower Monumental Dam (LMN) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
LMN	15APR	33	200.2	4.21	33	0.0000	0.000	33	0.030	0.030	33	0.000	0.000	33	0.000	0.000	33	0.000	0.000
	18APR	37	211.5	3.48	37	0.0000	0.000	37	0.135	0.069	37	0.108	0.052	37	0.054	0.038	37	0.000	0.000
	20APR	50	213.3	3.42	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	22APR	50	218.7	3.26	50	0.0060	0.006	50	0.040	0.028	50	0.120	0.046	50	0.000	0.000	50	0.020	0.020
	25APR	50	200.9	2.79	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	27APR	50	209.1	3.68	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	30APR	50	210.6	3.80	50	0.0000	0.000	50	0.080	0.048	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	02MAY	49	224.9	2.80	49	0.0000	0.000	49	0.020	0.020	49	0.000	0.000	49	0.000	0.000	49	0.000	0.000
	04MAY	50	215.6	3.38	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	06MAY	50	223.2	3.09	50	0.0040	0.004	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	08MAY	50	214.3	3.84	50	0.0040	0.004	50	0.060	0.034	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	10MAY	50	221.1	3.63	50	0.0040	0.004	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	12MAY	50	210.6	3.33	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	14MAY	50	215.3	4.09	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	16MAY	50	228.0	3.34	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	18MAY	50	219.3	3.78	50	0.0040	0.004	50	0.120	0.046	50	0.040	0.028	50	0.080	0.048	50	0.000	0.000
	20MAY	50	213.6	3.73	50	0.0460	0.037	50	0.120	0.046	50	0.000	0.000	50	0.060	0.034	50	0.000	0.000
	22MAY	50	202.7	4.39	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.060	0.044	50	0.000	0.000
	24MAY	50	211.0	3.84	50	0.0000	0.000	50	0.080	0.039	50	0.040	0.040	50	0.040	0.028	50	0.000	0.000
	26MAY	50	207.3	3.82	50	0.0000	0.000	50	0.040	0.028	50	0.040	0.040	50	0.020	0.020	50	0.000	0.000
	28MAY	50	225.3	3.04	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	30MAY	50	227.2	3.88	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01JUN	50	221.4	3.87	50	0.0000	0.000	50	0.160	0.060	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020
	03JUN	50	215.3	4.06	50	0.0000	0.000	50	0.260	0.069	50	0.040	0.028	50	0.140	0.050	50	0.000	0.000
	05JUN	50	216.0	3.85	50	0.0120	0.012	50	0.080	0.039	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	07JUN	50	223.3	3.88	50	0.0000	0.000	50	0.020	0.020	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000
	09JUN	50	207.2	3.86	50	0.0000	0.000	50	0.140	0.057	50	0.060	0.034	50	0.060	0.034	50	0.000	0.000
	11JUN	50	218.8	3.07	50	0.0000	0.000	50	0.200	0.064	50	0.040	0.028	50	0.080	0.063	50	0.000	0.000
	13JUN	50	213.4	3.76	50	0.0000	0.000	50	0.200	0.057	50	0.080	0.039	50	0.020	0.020	50	0.000	0.000
	15JUN	50	213.9	3.09	50	0.0000	0.000	50	0.100	0.052	50	0.000	0.000	50	0.120	0.055	50	0.000	0.000
	17JUN	50	207.8	3.38	50	0.0000	0.000	50	0.080	0.048	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	19JUN	50	219.2	3.61	50	0.0420	0.038	50	0.040	0.028	50	0.080	0.048	50	0.060	0.044	50	0.000	0.000
	21JUN	50	213.3	3.79	50	0.0000	0.000	50	0.320	0.073	50	0.080	0.048	50	0.020	0.020	50	0.000	0.000
	23JUN	27	217.2	6.20	27	0.0000	0.000	27	0.111	0.062	27	0.037	0.037	27	0.000	0.000	27	0.000	0.000
	25JUN	8	220.3	11.54	8	0.0000	0.000	8	0.125	0.125	8	0.000	0.000	8	0.000	0.000	8	0.000	0.000
	27JUN	3	236.7	6.01	3	0.0000	0.000	3	0.000	0.000	3	0.000	0.000	3	0.000	0.000	3	0.000	0.000
	29JUN	6	216.0	10.31	6	0.0000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000

Appendix 7. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at Rock Island Dam (RIS) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
RIS	22APR	100	151.9	2.59	100	1.4340	0.268	100	0.150	0.041	100	0.140	0.038	100	0.150	0.046	100	0.000	0.000
	24APR	88	147.3	2.57	88	5.6341	1.032	88	0.170	0.043	88	0.193	0.056	88	0.511	0.094	88	0.000	0.000
	26APR	99	151.6	2.31	99	8.1242	0.626	99	0.172	0.043	99	0.263	0.060	99	0.354	0.069	99	0.010	0.010
	29APR	100	146.4	2.13	100	9.4430	0.763	100	0.260	0.058	100	0.150	0.046	100	0.340	0.057	100	0.020	0.014
	01MAY	100	143.6	1.81	100	8.9250	0.912	100	0.500	0.059	100	0.420	0.079	100	0.660	0.097	100	0.020	0.014
	03MAY	100	139.4	1.83	100	9.4870	0.772	100	0.480	0.070	100	0.320	0.063	100	0.650	0.094	100	0.050	0.026
	06MAY	89	140.3	1.86	89	2.9494	0.641	89	0.202	0.051	89	0.292	0.060	89	0.528	0.083	89	0.022	0.016
	08MAY	100	141.5	1.65	100	0.0560	0.019	100	0.010	0.010	100	0.060	0.028	100	0.040	0.020	100	0.040	0.032
	10MAY	100	141.3	1.53	100	0.0640	0.022	100	0.010	0.010	100	0.040	0.024	100	0.110	0.031	100	0.000	0.000
	13MAY	100	145.2	1.59	100	0.1680	0.041	100	0.010	0.010	100	0.020	0.014	100	0.050	0.022	100	0.010	0.010
	15MAY	100	144.2	1.75	100	0.0950	0.023	100	0.010	0.010	100	0.000	0.000	100	0.060	0.028	100	0.000	0.000
	17MAY	100	144.4	1.66	100	0.0710	0.023	100	0.010	0.010	100	0.010	0.010	100	0.000	0.000	100	0.000	0.000
	20MAY	100	147.9	1.36	100	0.8540	0.116	100	0.000	0.000	100	0.020	0.014	100	0.020	0.014	100	0.020	0.020
	22MAY	100	150.8	1.68	100	0.1980	0.032	100	0.020	0.014	100	0.060	0.031	100	0.010	0.010	100	0.000	0.000
	24MAY	100	146.0	1.31	100	0.1580	0.029	100	0.010	0.010	100	0.060	0.024	100	0.060	0.037	100	0.000	0.000
	27MAY	100	152.6	1.52	100	0.0900	0.036	100	0.000	0.000	100	0.020	0.014	100	0.050	0.022	100	0.000	0.000
	29MAY	100	146.1	1.44	100	0.4390	0.065	100	0.050	0.033	100	0.070	0.033	100	0.030	0.017	100	0.010	0.010
	31MAY	100	149.7	1.63	100	0.2470	0.049	100	0.020	0.014	100	0.080	0.034	100	0.000	0.000	100	0.000	0.000
	03JUN	100	149.0	1.82	100	0.0400	0.012	100	0.040	0.020	100	0.130	0.042	100	0.040	0.024	100	0.000	0.000
	04JUN	100	145.9	1.92	100	0.0680	0.018	100	0.160	0.047	100	0.060	0.028	100	0.120	0.036	100	0.010	0.010
	05JUN	100	151.1	1.93	100	0.0210	0.008	100	0.150	0.054	100	0.050	0.026	100	0.020	0.014	100	0.000	0.000
	06JUN	100	152.9	1.99	100	0.0200	0.007	100	0.050	0.026	100	0.020	0.014	100	0.030	0.022	100	0.000	0.000
	07JUN	100	150.9	1.84	100	0.0350	0.008	100	0.080	0.027	100	0.110	0.042	100	0.000	0.000	100	0.000	0.000
	10JUN	100	148.7	1.81	100	0.0260	0.007	100	0.020	0.014	100	0.100	0.033	100	0.010	0.010	100	0.000	0.000
	12JUN	93	144.9	1.90	93	0.0247	0.009	93	0.043	0.026	93	0.129	0.041	93	0.054	0.028	93	0.011	0.011
	13JUN	7	139.0	6.47	7	0.0143	0.014	7	0.000	0.000	7	0.000	0.000	7	0.000	0.000	7	0.000	0.000
	14JUN	64	143.5	2.68	64	0.1094	0.026	64	0.063	0.030	64	0.094	0.053	64	0.031	0.022	64	0.000	0.000
	17JUN	73	146.0	3.37	73	0.3507	0.161	73	0.068	0.041	73	0.137	0.041	73	0.041	0.023	73	0.000	0.000
	18JUN	26	140.3	3.82	26	0.0538	0.019	26	0.231	0.115	26	0.192	0.096	26	0.038	0.038	26	0.000	0.000
	19JUN	100	133.4	2.04	100	0.4110	0.079	100	0.060	0.024	100	0.230	0.051	100	0.070	0.029	100	0.000	0.000
	21JUN	45	155.9	2.80	45	0.0244	0.012	45	0.022	0.022	45	0.000	0.000	45	0.044	0.031	45	0.000	0.000
	24JUN	22	146.2	3.46	22	0.0409	0.026	22	0.000	0.000	22	0.000	0.000	22	0.000	0.000	22	0.000	0.000
	25JUN	15	143.2	5.20	15	0.0000	0.000	15	0.000	0.000	15	0.133	0.091	15	0.000	0.000	15	0.000	0.000
	26JUN	24	153.1	5.21	24	0.0042	0.004	24	0.000	0.000	24	0.167	0.078	24	0.083	0.083	24	0.000	0.000
	01JUL	6	153.7	3.00	6	0.0000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000
	10JUL	2	145.0	8.00	2	0.0500	0.050	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000
	30JUL	2	146.5	6.50	2	0.0000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000
	05AUG	2	162.0	10.00	2	0.0000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000
	12AUG	2	156.5	2.50	2	0.0000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000	2	0.000	0.000

Appendix 8. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at McNary Dam (MCN) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

SITE	DATE	FORK LENGTH N	FORK LENGTH MEAN	FORK LENGTH STDERR	% OCC N	% OCC MEAN	% OCC STDERR	Caudal N	Caudal MEAN	Caudal STDERR	Anal N	Anal MEAN	Anal STDERR	Dorsal N	Dorsal MEAN	Dorsal STDERR	Eye N	Eye MEAN	Eye STDERR
MCN	19APR	34	159.8	4.08	34	0.0000	0.000	34	0.000	0.000	34	0.000	0.000	34	0.000	0.000	34	0.000	0.000
	21APR	50	163.3	2.10	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	24APR	50	165.7	1.87	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	26APR	50	165.2	2.38	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	28APR	50	165.6	2.40	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29APR	50	165.1	2.71	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01MAY	50	150.0	2.59	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	03MAY	50	156.6	2.45	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	05MAY	50	151.5	3.03	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020
	07MAY	25	154.5	3.84	25	0.0000	0.000	25	0.000	0.000	25	0.000	0.000	25	0.000	0.000	25	0.000	0.000
	09MAY	50	154.3	2.97	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	11MAY	50	160.6	2.66	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	13MAY	50	146.4	2.47	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	15MAY	29	149.6	3.52	29	0.0000	0.000	29	0.000	0.000	29	0.000	0.000	29	0.000	0.000	29	0.000	0.000
	17MAY	50	158.1	2.96	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	19MAY	50	154.0	2.87	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	21MAY	50	151.7	3.14	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	23MAY	50	152.0	2.76	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	25MAY	50	153.6	2.20	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	27MAY	50	151.4	2.05	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29MAY	50	149.2	2.57	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	31MAY	50	154.9	2.75	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	02JUN	50	152.8	2.37	50	0.0000	0.000	50	0.060	0.044	50	0.060	0.034	50	0.000	0.000	50	0.000	0.000
	04JUN	36	149.1	2.17	36	0.0000	0.000	36	0.056	0.039	36	0.000	0.000	36	0.000	0.000	36	0.000	0.000
	06JUN	44	154.8	2.89	44	0.0000	0.000	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000
	08JUN	21	152.9	6.06	21	0.0000	0.000	21	0.095	0.095	21	0.048	0.048	21	0.000	0.000	21	0.000	0.000
	10JUN	9	167.1	6.86	9	0.0000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000

Appendix 9. Sample size (N), mean and standard error (stderr) for steelhead sampled for signs of gas bubbles trauma at McNary Dam (MCN) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR
MCN	19APR	16	236.4	5.46	16	0.0000	0.000	16	0.000	0.000	16	0.000	0.000	16	0.000	0.000	16	0.000	0.000
	21APR	50	239.6	2.83	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	24APR	50	227.8	3.38	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	26APR	50	225.8	3.82	50	0.0000	0.000	50	0.040	0.040	50	0.060	0.060	50	0.060	0.060	50	0.000	0.000
	28APR	50	216.6	4.57	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	29APR	50	211.1	3.41	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	01MAY	50	206.0	3.86	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	03MAY	50	213.9	3.51	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	05MAY	50	236.5	3.88	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	07MAY	26	216.3	5.42	26	0.0000	0.000	26	0.000	0.000	26	0.000	0.000	26	0.000	0.000	26	0.000	0.000
	09MAY	50	225.4	3.48	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	11MAY	50	225.2	2.86	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	13MAY	50	222.0	3.69	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	15MAY	37	219.3	3.44	37	0.0000	0.000	37	0.000	0.000	37	0.000	0.000	37	0.000	0.000	37	0.081	0.081
	17MAY	50	226.6	3.83	50	0.0000	0.000	50	0.040	0.028	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000
	19MAY	50	227.7	4.13	50	0.0000	0.000	50	0.040	0.028	50	0.020	0.020	50	0.060	0.060	50	0.000	0.000
	21MAY	50	219.5	2.85	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	23MAY	50	227.0	4.60	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020
	25MAY	50	220.8	3.41	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	27MAY	50	229.1	3.27	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29MAY	50	230.4	4.03	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	31MAY	50	234.6	4.33	50	0.0380	0.038	50	0.020	0.020	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000
	02JUN	35	233.4	4.08	35	0.0000	0.000	35	0.086	0.048	35	0.029	0.029	35	0.000	0.000	35	0.000	0.000
	04JUN	31	225.0	5.06	31	0.0000	0.000	31	0.161	0.082	31	0.097	0.071	31	0.000	0.000	31	0.065	0.065
	06JUN	23	238.5	6.10	23	0.0000	0.000	23	0.087	0.060	23	0.087	0.087	23	0.087	0.087	23	0.000	0.000
	08JUN	26	235.4	6.65	26	0.0000	0.000	26	0.115	0.064	26	0.038	0.038	26	0.000	0.000	26	0.000	0.000
	10JUN	14	211.3	9.28	14	0.0000	0.000	14	0.000	0.000	14	0.000	0.000	14	0.000	0.000	14	0.000	0.000
	12JUN	6	205.2	11.92	6	0.0000	0.000	6	0.167	0.167	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000
	14JUN	12	226.3	5.58	12	0.0000	0.000	12	0.000	0.000	12	0.000	0.000	12	0.000	0.000	12	0.000	0.000
	16JUN	10	257.7	5.20	10	0.0000	0.000	10	0.100	0.100	10	0.000	0.000	10	0.000	0.000	10	0.000	0.000
	18JUN	15	238.7	3.57	15	0.0000	0.000	15	0.467	0.192	15	0.200	0.145	15	0.000	0.000	15	0.000	0.000
	20JUN	7	271.6	7.80	7	0.0000	0.000	7	0.000	0.000	7	0.000	0.000	7	0.000	0.000	7	0.000	0.000
	22JUN	4	242.0	11.47	4	0.0000	0.000	4	0.000	0.000	4	0.000	0.000	4	0.000	0.000	4	0.000	0.000

Appendix 10. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at John Day Dam (JDA) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
		N	MEAN	STDERR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR
SITE	DATE																		
JDA	16APR	28	166.6	4.05	28	0.0107	0.011	28	0.000	0.000	28	0.000	0.000	28	0.000	0.000	28	0.000	0.000
	18APR	50	166.4	2.69	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	20APR	44	167.1	1.95	44	0.0000	0.000	44	0.000	0.000	44	0.000	0.000	44	0.023	0.023	44	0.000	0.000
	23APR	50	169.6	1.43	50	0.0040	0.003	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	25APR	50	172.3	2.26	50	0.0020	0.002	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	27APR	24	166.9	2.58	24	0.0000	0.000	24	0.000	0.000	24	0.000	0.000	24	0.000	0.000	24	0.042	0.042
	30APR	45	171.8	3.53	45	0.0000	0.000	45	0.000	0.000	45	0.000	0.000	45	0.022	0.022	45	0.044	0.044
	02MAY	47	160.5	3.04	47	0.0000	0.000	47	0.000	0.000	47	0.000	0.000	47	0.000	0.000	47	0.043	0.030
	04MAY	38	166.4	4.12	38	0.0105	0.011	38	0.000	0.000	38	0.000	0.000	38	0.000	0.000	38	0.026	0.026
	06MAY	31	178.7	3.88	31	0.0000	0.000	31	0.065	0.045	31	0.065	0.045	31	0.129	0.077	31	0.000	0.000
	08MAY	35	167.9	3.85	35	0.0000	0.000	35	0.000	0.000	35	0.000	0.000	35	0.057	0.040	35	0.000	0.000
	10MAY	26	155.6	5.47	26	0.0038	0.004	26	0.000	0.000	26	0.000	0.000	26	0.000	0.000	26	0.000	0.000
	12MAY	25	154.2	4.23	25	0.0080	0.006	25	0.040	0.040	25	0.000	0.000	25	0.000	0.000	25	0.000	0.000
	14MAY	50	154.9	2.63	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	16MAY	46	143.8	2.34	46	0.0000	0.000	46	0.000	0.000	46	0.000	0.000	46	0.000	0.000	46	0.000	0.000
	18MAY	33	152.6	2.68	33	0.0000	0.000	33	0.000	0.000	33	0.000	0.000	33	0.000	0.000	33	0.000	0.000
	20MAY	30	150.6	2.98	30	0.0033	0.003	30	0.000	0.000	30	0.000	0.000	30	0.000	0.000	30	0.000	0.000
	22MAY	50	149.9	1.85	50	0.0140	0.014	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	24MAY	13	148.7	4.28	13	0.0077	0.008	13	0.000	0.000	13	0.000	0.000	13	0.000	0.000	13	0.000	0.000
	26MAY	44	150.2	2.53	44	0.0432	0.015	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000
	28MAY	44	152.5	1.71	44	0.0068	0.007	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000
	30MAY	29	142.1	2.45	29	0.0000	0.000	29	0.000	0.000	29	0.000	0.000	29	0.000	0.000	29	0.000	0.000
	01JUN	25	150.4	2.72	25	0.0000	0.000	25	0.000	0.000	25	0.000	0.000	25	0.040	0.040	25	0.000	0.000
	03JUN	34	147.1	2.13	34	0.1059	0.047	34	0.176	0.089	34	0.000	0.000	34	0.029	0.029	34	0.000	0.000
	05JUN	38	152.4	1.89	38	0.0000	0.000	38	0.000	0.000	38	0.026	0.026	38	0.000	0.000	38	0.000	0.000

Appendix 11. Sample size (N), mean and standard error (stderr) for steelhead sampled for signs of gas bubbles trauma at John Day Dam (JDA) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
JDA	16APR	11	212.1	10.63	11	0.0000	0.000	11	0.000	0.000	11	0.000	0.000	11	0.000	0.000	11	0.000	0.000
	18APR	23	199.7	6.06	23	0.0000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000
	20APR	18	199.4	7.00	18	0.0000	0.000	18	0.222	0.129	18	0.000	0.000	18	0.056	0.056	18	0.000	0.000
	23APR	44	218.4	3.14	44	0.0068	0.007	44	0.023	0.023	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000
	25APR	50	233.1	2.39	50	0.0060	0.006	50	0.000	0.000	50	0.060	0.044	50	0.020	0.020	50	0.000	0.000
	27APR	50	203.9	3.56	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	30APR	46	202.6	4.11	46	0.0022	0.002	46	0.130	0.074	46	0.065	0.037	46	0.022	0.022	46	0.022	0.022
	02MAY	50	203.7	3.05	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020
	04MAY	36	204.1	4.14	36	0.0000	0.000	36	0.056	0.039	36	0.000	0.000	36	0.000	0.000	36	0.000	0.000
	06MAY	38	217.9	4.34	38	0.0000	0.000	38	0.000	0.000	38	0.000	0.000	38	0.000	0.000	38	0.000	0.000
	08MAY	34	205.5	4.47	34	0.0000	0.000	34	0.000	0.000	34	0.029	0.029	34	0.000	0.000	34	0.000	0.000
	10MAY	17	211.8	5.96	17	0.0176	0.018	17	0.000	0.000	17	0.000	0.000	17	0.000	0.000	17	0.000	0.000
	12MAY	23	206.2	6.47	23	0.0000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000
	14MAY	35	216.2	4.43	35	0.0000	0.000	35	0.000	0.000	35	0.000	0.000	35	0.000	0.000	35	0.000	0.000
	16MAY	50	189.1	2.90	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	18MAY	51	194.7	4.30	51	0.0157	0.014	51	0.000	0.000	51	0.020	0.020	51	0.000	0.000	51	0.000	0.000
	20MAY	34	215.5	4.79	34	0.0000	0.000	34	0.000	0.000	34	0.000	0.000	34	0.000	0.000	34	0.029	0.029
	22MAY	50	205.0	3.89	50	0.0040	0.003	50	0.120	0.046	50	0.100	0.043	50	0.020	0.020	50	0.000	0.000
	24MAY	33	218.4	5.16	33	0.0030	0.003	33	0.091	0.067	33	0.000	0.000	33	0.061	0.042	33	0.000	0.000
	26MAY	45	211.4	4.51	45	0.0044	0.003	45	0.044	0.031	45	0.000	0.000	45	0.000	0.000	45	0.000	0.000
	28MAY	37	218.7	4.73	37	0.0162	0.016	37	0.027	0.027	37	0.000	0.000	37	0.000	0.000	37	0.000	0.000
	30MAY	20	204.0	6.48	20	0.0000	0.000	20	0.000	0.000	20	0.000	0.000	20	0.000	0.000	20	0.000	0.000
	01JUN	27	222.1	5.55	27	0.0000	0.000	27	0.222	0.082	27	0.000	0.000	27	0.074	0.051	27	0.000	0.000
	03JUN	35	226.8	4.64	35	0.0914	0.031	35	0.571	0.149	35	0.171	0.104	35	0.000	0.000	35	0.000	0.000
	05JUN	37	239.0	3.40	37	0.0000	0.000	37	0.297	0.094	37	0.027	0.027	37	0.054	0.038	37	0.000	0.000
	07JUN	14	227.2	8.85	14	0.0214	0.021	14	0.071	0.071	14	0.000	0.000	14	0.000	0.000	14	0.000	0.000
	09JUN	18	224.3	9.07	18	0.0000	0.000	18	0.111	0.076	18	0.056	0.056	18	0.000	0.000	18	0.000	0.000
	11JUN	5	224.6	21.16	5	0.0000	0.000	5	0.000	0.000	5	0.000	0.000	5	0.000	0.000	5	0.000	0.000

Appendix 12. Sample size (N), mean and standard error (stderr) for spring chinook salmon sampled for signs of gas bubbles trauma at Bonneville Dam (BON) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
BON	15APR	24	144.6	5.93	24	0.0000	0.000	24	0.000	0.000	24	0.000	0.000	24	0.042	0.042	24	0.042	0.042
	17APR	39	159.3	4.46	39	0.0000	0.000	39	0.000	0.000	39	0.000	0.000	39	0.026	0.026	39	0.000	0.000
	19APR	44	148.4	4.06	44	0.0841	0.070	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000	44	0.000	0.000
	22APR	50	147.1	2.80	50	0.0080	0.008	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.020	0.020
	24APR	50	150.8	3.41	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	26APR	50	149.4	2.80	50	0.0000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.040	0.028	50	0.000	0.000
	29APR	50	155.2	2.80	50	0.0180	0.018	50	0.020	0.020	50	0.000	0.000	50	0.040	0.040	50	0.000	0.000
	01MAY	50	155.1	2.89	50	0.0000	0.000	50	0.040	0.040	50	0.000	0.000	50	0.040	0.040	50	0.000	0.000
	03MAY	51	148.7	2.28	51	0.0000	0.000	51	0.000	0.000	51	0.000	0.000	51	0.020	0.020	51	0.000	0.000
	05MAY	50	141.2	3.09	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	07MAY	51	147.4	2.54	51	0.0137	0.010	51	0.039	0.027	51	0.000	0.000	51	0.000	0.000	51	0.000	0.000
	09MAY	28	146.1	4.08	28	0.0250	0.019	28	0.000	0.000	28	0.000	0.000	28	0.036	0.036	28	0.000	0.000
	11MAY	51	150.8	2.35	51	0.0882	0.081	51	0.020	0.020	51	0.000	0.000	51	0.000	0.000	51	0.000	0.000
	13MAY	50	159.5	3.21	50	0.0000	0.000	50	0.020	0.020	50	0.000	0.000	50	0.100	0.052	50	0.000	0.000
	15MAY	51	152.8	2.62	51	0.0431	0.029	51	0.000	0.000	51	0.000	0.000	51	0.020	0.020	51	0.000	0.000
	17MAY	11	148.7	4.85	11	0.0000	0.000	11	0.000	0.000	11	0.000	0.000	11	0.000	0.000	11	0.000	0.000
	19MAY	24	149.3	3.88	24	0.0000	0.000	24	0.000	0.000	24	0.000	0.000	24	0.000	0.000	24	0.000	0.000
	21MAY	43	153.2	2.74	43	0.0186	0.013	43	0.070	0.039	43	0.000	0.000	43	0.000	0.000	43	0.000	0.000
	23MAY	35	153.6	2.66	35	0.0000	0.000	35	0.000	0.000	35	0.000	0.000	35	0.029	0.029	35	0.000	0.000
	25MAY	48	146.1	1.84	48	0.0083	0.008	48	0.000	0.000	48	0.000	0.000	48	0.021	0.021	48	0.000	0.000
	27MAY	50	147.9	2.14	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	29MAY	50	156.4	2.06	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.080	0.039	50	0.000	0.000
	31MAY	50	149.5	2.32	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	02JUN	50	146.8	1.85	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.000	0.000
	04JUN	17	158.1	3.91	17	0.0000	0.000	17	0.000	0.000	17	0.118	0.118	17	0.000	0.000	17	0.000	0.000
	06JUN	23	161.3	2.73	23	0.0000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000	23	0.000	0.000
	08JUN	6	155.7	8.72	6	0.0000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000	6	0.000	0.000

Appendix 13. Sample size (N), mean and standard error (stderr) for steelhead sampled for signs of gas bubbles trauma at Bonneville Dam (BON) in 1996. Mean percent occlusion (% OCC) represents the sum of percent of lateral line bubbles divided by total fish sampled. Mean of fins and eyes represents the sum of the code rating divided by total fish sampled.

		FORK LENGTH			% OCC			Caudal			Anal			Dorsal			Eye		
SITE	DATE	N	MEAN	STDERR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR	N	MEAN	STDE-RR
BON	15APR	9	218.8	6.62	9	0.0000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000	9	0.000	0.000
	17APR	22	202.0	5.87	22	0.0000	0.000	22	0.182	0.125	22	0.136	0.100	22	0.091	0.091	22	0.000	0.000
	19APR	18	207.6	7.69	18	0.0000	0.000	18	0.000	0.000	18	0.000	0.000	18	0.056	0.056	18	0.000	0.000
	22APR	22	201.4	5.08	22	0.0000	0.000	22	0.045	0.045	22	0.091	0.091	22	0.091	0.063	22	0.000	0.000
	24APR	38	215.1	3.80	38	0.0105	0.011	38	0.053	0.053	38	0.132	0.077	38	0.132	0.077	38	0.000	0.000
	26APR	48	226.4	3.41	48	0.0000	0.000	48	0.000	0.000	48	0.104	0.061	48	0.000	0.000	48	0.000	0.000
	29APR	50	220.2	2.98	50	0.0260	0.026	50	0.040	0.040	50	0.160	0.072	50	0.060	0.060	50	0.000	0.000
	01MAY	47	216.1	4.15	47	0.0000	0.000	47	0.021	0.021	47	0.234	0.092	47	0.064	0.064	47	0.000	0.000
	03MAY	52	214.8	2.75	52	0.0000	0.000	52	0.058	0.043	52	0.019	0.019	52	0.000	0.000	52	0.000	0.000
	05MAY	51	205.3	3.35	51	0.0000	0.000	51	0.000	0.000	51	0.020	0.020	51	0.020	0.020	51	0.000	0.000
	07MAY	51	212.7	3.40	51	0.0000	0.000	51	0.000	0.000	51	0.000	0.000	51	0.039	0.027	51	0.000	0.000
	09MAY	42	206.6	3.72	42	0.0071	0.007	42	0.000	0.000	42	0.000	0.000	42	0.048	0.033	42	0.000	0.000
	11MAY	29	215.0	3.85	29	0.0000	0.000	29	0.000	0.000	29	0.000	0.000	29	0.000	0.000	29	0.000	0.000
	13MAY	52	212.9	3.66	52	0.0000	0.000	52	0.019	0.019	52	0.115	0.065	52	0.000	0.000	52	0.000	0.000
	15MAY	36	209.6	4.36	36	0.0056	0.006	36	0.000	0.000	36	0.000	0.000	36	0.028	0.028	36	0.028	0.028
	17MAY	25	207.9	3.56	25	0.0000	0.000	25	0.040	0.040	25	0.120	0.120	25	0.040	0.040	25	0.000	0.000
	19MAY	52	213.2	3.39	52	0.0000	0.000	52	0.000	0.000	52	0.000	0.000	52	0.000	0.000	52	0.000	0.000
	21MAY	50	229.0	3.65	50	0.0060	0.006	50	0.240	0.073	50	0.200	0.090	50	0.200	0.081	50	0.020	0.020
	23MAY	51	218.8	3.34	51	0.0000	0.000	51	0.098	0.064	51	0.078	0.062	51	0.059	0.033	51	0.000	0.000
	25MAY	50	215.9	3.80	50	0.0000	0.000	50	0.080	0.048	50	0.000	0.000	50	0.040	0.028	50	0.000	0.000
	27MAY	50	214.9	3.38	50	0.0000	0.000	50	0.000	0.000	50	0.000	0.000	50	0.020	0.020	50	0.000	0.000
	29MAY	50	224.7	3.80	50	0.0000	0.000	50	0.040	0.028	50	0.000	0.000	50	0.060	0.034	50	0.000	0.000
	31MAY	50	235.6	3.52	50	0.0000	0.000	50	0.060	0.044	50	0.040	0.040	50	0.060	0.034	50	0.000	0.000
	02JUN	34	219.6	4.33	34	0.0000	0.000	34	0.147	0.105	34	0.118	0.082	34	0.059	0.059	34	0.000	0.000
	04JUN	26	233.0	5.70	26	0.0000	0.000	26	0.115	0.085	26	0.077	0.077	26	0.038	0.038	26	0.000	0.000
	06JUN	34	222.0	5.46	34	0.1118	0.073	34	0.324	0.109	34	0.029	0.029	34	0.147	0.075	34	0.029	0.029